P 35.1
2,3
c 2

COMMONWEALTH OF PENNSYLVANIA

DEPARTMENT OF INTERNAL AFFAIRS

URANIUM

IN

PENNSYLVANIA

By

John F. McCauley

TOPOGRAPHIC AND GEOLOGIC SURVEY

BULLETIN M43

1961

G1 5 1961

PENNSYLVANIA STATE LIBRARY
DOCUMENTS SECTION

Digitized by the Internet Archive
in 2016 with funding from
This project is made possible by a grant from the Institute of Museum and Library Services as administered by the Pennsylvania Department of Education through the Office of Commonwealth Libraries

https://archive.org/details/uraniuminpennsyl00mcca

URANIUM IN PENNSYLVANIA

Uraniferous sandstone specimens from the Catskill Formation in Pennsylvania. Yellow mineral is carnotite, green is malachite, blue is azurite, and black is coalified plant fragments.

PENNSYLVANIA
GEOLOGICAL
SURVEY

Bulletin M 43

URANIUM
IN
PENNSYLVANIA

By

John F. McCauley

DEPARTMENT OF INTERNAL AFFAIRS
GENEVIEVE BLATT, *Secretary*

TOPOGRAPHIC AND GEOLOGIC SURVEY
CARLYLE GRAY, *State Geologist*
Harrisburg, Pa.

1961

Copyrighted 1961
by the
Commonwealth of Pennsylvania

Quotations from this book may be published if credit is given to
the Pennyslvania Geological Survey

ADDITIONAL COPIES
OF THIS PUBLICATION MAY BE PURCHASED FROM
BUREAU OF PUBLICATIONS
DEPARTMENT OF PROPERTY AND SUPPLIES
HARRISBURG, PA.

CONTENTS

	Page
Abstract	1
Introduction	1
Purpose and method of presentation	1
Acknowledgements	2
Uranium occurrences in Triassic rocks	2
General stratigraphy and structure	2
Delaware Valley stratigraphy	4
Igneous Rocks	4
Uranium occurrences	6
Hendricks Island	6
Prallsville	6
Raven Rock	6
Mineralogy and petrology	7
X-ray spectrographic analysis	8
Uranium occurrences in Mississippian rocks	9
Carbon County	9
Introduction	9
Stratigraphy	9
Mt. Pisgah	10
General description	10
Petrology	11
Mineralogy	11
X-ray spectrographic analysis	12
Huntingdon County	12
Location	12
Stratigraphy and structure	12
Petrology and mineralogy	14
X-ray spectrographic analysis	16
Uranium occurrences in Devonian rocks	17
Introduction	17
Stratigraphy	17
Catskill Formation	17
Pocono Formation	19
Marine Devonian	19

	Page
Stratigraphic control	20
Structure	20
Structural control	23
Description of significant occurrences	23
General characteristics of mineralized zones	23
Petrology	26
Mineralogy	27
Polished section studies	30
Mode of occurrence of the uranium	39
X-ray spectrographic analysis	39
The coloration problem	40
Bornite—chalcopyrite unmixing textures	42
Sulfur isotope study	44
Genesis of uranium occurrences in Pennsylvania	47
Review of previous genetic theories	47
Conclusions	48
Uranium occurrences in Precambrian rocks	51
Introduction	51
General description	51
Petrology and mineralogy	52
Genesis	53
Economic potential of sedimentary type occurrences	53
Bibliography	54
General references	56
Appendix A	57
Appendix B	69

ILLUSTRATIONS

FIGURES

			Page
FIGURE	1.	Index map of uranium occurrences	3
	2.	Geologic map of the Stockton-Lambertville area	pocket
	3.	Hendricks Island occurrence	7
	4.	Mt. Pisgah occurrence	pocket
	5.	Geologic map of the Round Knob area	13
	6.	View of Round Knob occurrence	14
	7.	Geologic map of the New Albany, Beaver Lake, and Central uranium areas	pocket
	8.	Geologic cross sections	21
	9.	Isometric diagram of the stratigraphic positions of the Devonian occurrences	22
	10.	Geologic cross section from Almedia to New Albany	24
	11.	Sulfur isotope ratios for Pennsylvania compared with standard ranges	46
	12.	Prospect 43	52
	13.	Prospect 22, Beaver Lake area	pocket

PLATES

PLATE	1.	Gray arkosic sandstone containing angular quartz and feldspar in a clay and limonite matrix	8
	2.	Zone "B." Red-gray radioactive siltstone containing angular to subangular quartz, along with muscovite and biotite in a sericite-chloritc matrix	15
	3.	A. Red subgraywacke 20 feet from ore zone at Prospect 31	28
		B. Gray subgraywacke from the ore zone at Prospect 31	28
	4.	A. Small isolated remnants of pyrite replaced by bornite which is replaced by galena	33
		B. Carbonaceous material replaced by galena with only shreds of the original material remaining	33
	5.	A. Bornite occupying cell interiors and rimmed by covellite	34
		B. Sheaf-like barite gangue replaced by chalcocite	34
	6.	A. Subhedral quartz crystal surrounded and embayed by galena which replaces vitrain along fractures	35

Page

B. Relict cell textures preserved by chalcocite and covellite 35
7. A. Pyrite occurring as stringers and as blebs within vitrain and replaced by chalcocite 36
B. Orthorhombic cleavage pattern in chalcocite 36
8. A. Chalcocite stringer replacing surrounding siltstone .. 37
B. Bornite containing very fine exsolution lamellae of chalcopyrite 37
9. A. Part of specimen shown in Plate 8B after heating at 200° C for 144 hours, quenching, and repolishing 38
B. Bornite after heating for 170 hours at 300° C 38

TABLES

TABLE 1. Stockton Formation 5
2. A part of the stratigraphic section reported in Klemic and Baker 10
3. Analyses of carbonaceous material 25
4. Method of identification of minerals identified from the ore zones 29
5. Clay mineral analysis 30
6. Bornite specimens heated for various lengths of time.. 43
7. Sulfur isotope ratios of uranium-sulfide occurrences in Pennsylvania 45

Appendix
1. X-ray spectrographic analysis 69
2. X-ray spectrographic analysis 70
3. X-ray spectrographic analysis 70
4. X-ray spectrographic analysis 71

URANIUM IN PENNSYLVANIA

ABSTRACT

Forty-three uranium occurrences, presently uneconomic, were studied primarily within the Commonwealth of Pennsylvania. The great majority are in the Catskill Formation of Devonian age and are of the "sandstone type." Similar occurrences are present in rocks of Mississippian and Triassic ages.

The occurrences are in gray to green zones within red bed formations of continental origin. Mineralization is commonly associated with carbonaceous material in the form of plant fragments. Pyrite, bornite, chalcopyrite, galena, digenite, chalcocite and covellite have been identified from the Devonian occurrences along with the secondary uranium minerals, uranospinite and metazeunerite. No primary uranium minerals could be identified and it is believed the primary uranium occurs either as a urano-organic compound or as an oxide, very finely disseminated throughout the carbon.

X-ray spectographic analysis shows that uranium, vanadium, iron, copper, lead, zinc, barium and arsenic are present in varying quantities in the majority of the sandstone occurrences. Uranium is the most abundant element in the Triassic occurrences, while the Mississippian are characterized by uranium and vanadium, and the Devonian by copper and uranium.

Chalcopyrite occurs in an exsolution relationship with bornite. Experimental data indicates that the minimum temperature of formation of this pair may be less than 100° C. Sulfur isotope studies show significant depletion in S^{34}, although variation within single occurrences is not as pronounced as for the Colorado Plateau deposits. This evidence suggests that the sulfur in the occurrences was derived from organically produced hydrogen sulfide.

The supergene and multiple-migration accretion genetic hypotheses are rejected. The sulfur isotope data favors the "ground water hydrothermal theory," although the possibility that some or all of the metals in these occurrences are derived from magmatic sources by lateral migration cannot be excluded.

INTRODUCTION

Purpose and Method of Presentation

Early in 1956 the Pennsylvania Geological Survey decided to support a study which would attempt to locate, describe and discuss the origin of the numerous uranium occurrences within the state. Field work was done during the summers of 1956 and 1957 while the writer was employed by the

Survey as a cooperating geologist. Laboratory work was carried on at Columbia University during the latter part of 1957 and the early part of 1958 and the summer and fall of 1958 were spent preparing this report.

The occurrences are in rocks of four different ages: Triassic, Mississippian, Devonian, and Precambrian. They are discussed in order of increasing age of the host rock. The Devonian occurrences are the most numerous and have received the greatest attention.

Acknowledgments

The special thanks of the writer are extended to Dr. Carlyle Gray, Director of the Pennsylvania Geological Survey, who formulated the project and assisted greatly in its execution. The author is grateful to Prof. Chas. H. Behre, Jr., of Columbia University who supervised the research both in the field and laboratory. Thanks are also extended to the following members of the Pennsylvania Geological Survey for their help: Dr. Arthur A. Socolow for his field visits and Dr. Davis M. Lapham for his mineralogical assistance. Prof. Paul F. Kerr, Columbia University, contributed numerous helpful suggestions in addition to making available the X-ray equipment of the Mineralogy Department. Mr. Joseph Durek, Mr. William Bassett, and the late Miss P. K. Hamilton of Columbia University aided in discussion of various aspects of the report. Prof. M. L. Jensen and Mr. Cyrus Field of Yale University provided valuable sulfur isotope data. Mention should also be made of the many prospectors whose help was invaluable in locating the occurrences. The author's wife, Camilla, assisted in some of the field work, drafted the preliminary illustrations, and helped in the report preparation.

URANIUM OCCURRENCES IN TRIASSIC ROCKS

General Stratigraphy and Structure

The Triassic continental sediments, usually designated as the Newark Series, are part of a belt which crops out discontinuously in a northeasterly direction from South Carolina to Nova Scotia. As generally interpreted, one side of the belt is marked by major faulting and the other by an unconformity on Paleozoic or Precambrian rocks.

According to Johnson and McLaughlin (1957), the group is divided into a lower arkosic formation and an upper red shale and sandstone formation containing some conglomerate. The formations intertongue and are not time-stratigraphic units but lithofacies. In the Delaware Valley they are separated by a third formation consisting of red, gray, and black argillite and shale.

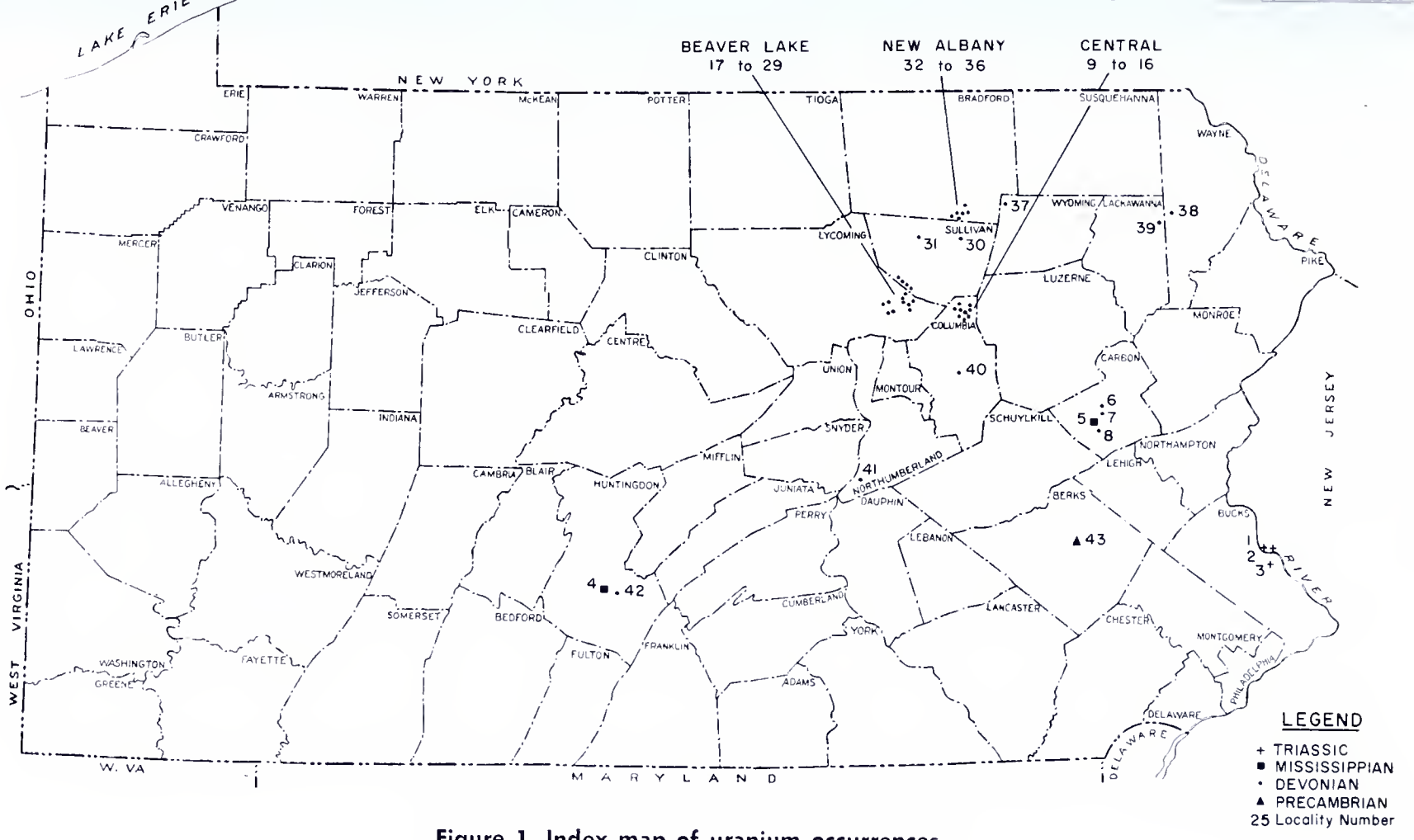


Figure 1. Index map of uranium occurrences.

Evidence of igneous activity is widespread, with large basaltic sills and dikes common throughout the entire belt. Extrusives are present locally, particularly in northern New Jersey, the Connecticut Valley, and at two places in Pennsylvania. Mineral deposits of hydrothermal origin are found in the vicinity of the uranium occurrences. West of Doylestown is an abandoned lead-zinc property called the New Galena Mine (Earl, 1950b). Another lead-zinc property is located at Pickering Creek in Chester County (Reed, 1949). A copper mine at Perkiomen Creek in Montgomery County is reported to have produced about 12,000 tons of ore from a vein in which the major ore mineral was chalcopyrite (Earl, 1950c).

The sediments and igneous rocks are faulted, tilted, or broadly warped throughout the Triassic belt. Most of the faults are small but displacements of several thousand feet do exist, particularly in the general area of the mineral occurrences (Fig. 2).

Delaware Valley Stratigraphy

The Newark Series in the Delaware Valley consists of three formations: (1) the Stockton, (2) the Lockatong, and (3) the Brunswick.

The uranium occurrences are in the Stockton Formation which is about 5,000 feet thick and consists of red, fine-grained sandstones and shales, coarse- to fine-grained arkose, and local conglomerate. It has been subdivided by Johnson and McLaughlin (1957) into five members (Table 1). Two of the occurrences are in the Upper Prallsville Member, 2,500 feet from the base of the formation and the third is in the Raven Rock Member, 4,300 feet from the base.

Igneous Rocks

The uppermost Brunswick Formation contains the greatest number of intrusives. A diabase sill, 1,000 feet thick, traverses the Delaware Valley just south of Lambertville. At Bowman Hill, farther to the south, a diabase dike on the west side of the river cuts the enclosing sediments vertically and appears to have been a feeder of the sill. North of Lambertville, an intrusive cut off by a fault on the north also shows transgressive relations and is interpreted as a feeder for the sills higher in the section (Fig. 2). Augite and labradorite, An_{50}, are the major constituents along with the accessories, magnetite, orthoclase, quartz and biotite. The alteration products are sericite, kaolinite, and chlorite. Numerous vertical fractures are filled with calcite.

Table 1

Stockton Formation

After Johnson and McLaughlin, 1957

Member	Description	Thickness
	Red and brown sandstone, minor arkose	724 feet
Raven Rock	Massive, medium- to coarse-grained, white and gray arkose (Raven Rock uranium occurrence)	293
	Red and gray fine-grained sandstone and red shale, with minor arkose	787
Cutalossa	Medium- to coarse-grained, thick-bedded arkose with interbeds of red-brown, fine-grained sandstone	232
	Red and brown, fine-grained sandstone, red shale, and minor arkose	373
Upper Prallsville	Thick-bedded, medium- to coarse-grained arkose with red sandstone interbeds (Hendricks Island and Prallsville uranium occurrences)	205
	Red and brown sandstone and red shale	136
Lower Prallsville	Thick-bedded, coarse-grained, white, gray and yellow arkose, with interbeds of fine-grained red sandstone	474
	Fine-grained red sandstone (poorly exposed)	447
	Thick-bedded, medium-grained gray arkose with minor conglomerate	224
Solebury	Thick-bedded to massive, coarse-grained quartz-arkose conglomerate with interbedded arkose, red shale, and sandstone	387
	Arkose, red shale and sandstone, minor conglomerate	720
	TOTAL	5,002 feet

Uranium Occurrences

Hendricks Island (Prospect 1)

The radioactive zone, consisting of yellow to brown ferruginous siltstone, is located in an abandoned brownstone quarry directly opposite the western tip of Hendricks Island in the Delaware River. It is 1 to 2 feet thick and conformable with bedding in the quarry walls for about 150 feet (Fig. 3). Both ends of the zone are obscured so that its actual extent cannot be determined. No radioactivity was noted two hundred feet behind the NE-SW quarry wall where a small stream cuts below the level of the mineralized horizon. The rock for about 10 feet on either side of the mineralized zone is coarse gray arkosic sandstone speckled with brown iron oxides. Farther away the sandstone is reddish in color and finer grained.

Radioactivity is irregular throughout the zone, ranging from background to .7 mr/hr. The major portion of the zone averages about .15 mr/hr. No uranium minerals were observed in the field, nor in laboratory studies. However, X-ray spectrographic analysis did establish the presence of uranium and the absence of thorium.

Prallsville (Prospect 2)

At this occurrence, 200 yards west of the bridge across Wickeocheoke Creek on Rt. 29, radioactivity emanates from a coarse-grained gray arkosic sandstone speckled with brown iron oxides. The radioactivity has been traced for 200 yards across Rt. 29, but the exposure is so poor that exact field relationships cannot be determined. A ferruginous zone like those containing the major portion of the radioactivity at the other localities was not observed. McLaughlin (1957, p. 61) reports that chemical analysis on four selected samples collected by the U.S. Geological Survey in 1950 showed a U_3O_8 content ranging from 0.09 to 1.28 percent. Disseminated throughout the arkose is the secondary uranium mineral, metazeunerite, $Cu(UO_2)_2AsO_4)_2 \cdot 8H_2O$, identified by X-ray powder photograph and confirmed by X-ray spectrography.

Carbonaceous material was not observed at any of the three occurrences, but since the sediments are predominantly stream deposits, it may be present in the unoxidized portions of the section. Hydrogen sulfide given off by this carbonaceous material may have migrated into stratigraphic traps, and resulted in precipitation of metals from mineralizing solutions.

Raven Rock (Prospect 3)

Radioactivity is confined to a deeply weathered limonite zone 30 feet from the base of the eastern wall of Raven Rock Quarry, 2 miles northeast of Point Pleasant. It is roughly conformable with bedding, 4 to 6 feet in width, and can be traced laterally for more than 100 feet. Coarse-grained,

gray arkosic sandstone speckled with brown iron oxides surrounds this zone, and, as at Hendricks Island, grades vertically into finer-grained, reddish sandstone.

The mineralized zone was not accessible, but samples from it were collected on the floor of the quarry. Radioactivity varied considerably; the highest reading obtained was 0.5 mr/hr. The secondary uranium mineral, meta-autunite, $Ca\ (UO_2)_2(PO_4)_2.2\frac{1}{2}—6\frac{1}{2}\ H_2O$, identified from an X-ray powder photograph, is present in minute quantities.

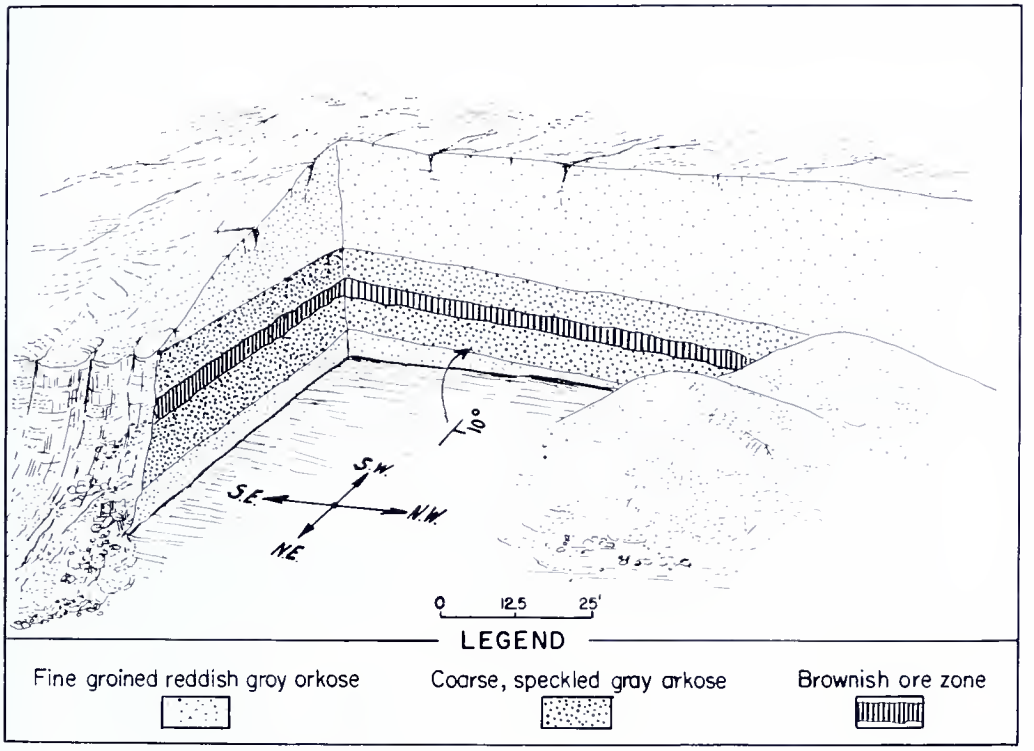


Figure 3. Hendricks Island occurrence.

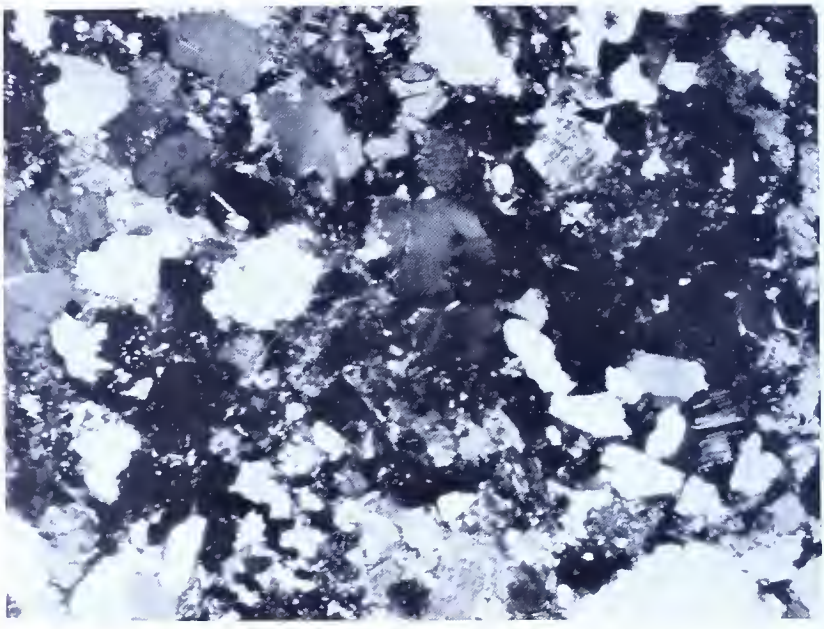
Mineralogy and Petrology

In thin section, the arkosic sandstone immediately adjacent to the mineralization consists of unsorted silt (0.01-0.05mm) to coarse sand size (0.5-1.5mm) quartz and feldspar grains. The total feldspar content is about 10 percent. Many of the grain contacts are sutured, indicating post depositional recrystallization (Pl.1). This feature is also noted in the copper-uranium occurrences described later. The feldspars are kaolinized and locally sericitized. Both the quartz and feldspar are replaced along grain boundaries by limonite. A few unoxidized grains of euhedral pyrite are seen, surrounded by limonite rims. Limonite, which is responsible for the speckled appearance of the rock, is abundant in the interstices, as are minor

amounts of calcite and chlorite (Pl. 1). Some specular hematite is present both in the mineralized zones and the surrounding host rocks.

The ferruginous radioactive zones at Hendricks Island and Raven Rock are characterized by a variety of shades of red, yellow, and brown. These colors are due to the presence of hematite, jarosite, and goethite in varying quantities. The presence of each was verified by X-ray diffractometer analysis. The Raven Rock occurrence contains abundant pyrite in irregular nodules elongated parallel to the bedding. Pyrite was noted in lesser quantities at the other two occurrences. Generally, the pyrite appears to be more abundant near the ore zones. Minor quantities of zircon, tourmaline, ilmenite, and topaz are present both in the host rocks and the mineralized zones.

Plate 1



Gray arkosic sandstone (Prospect 1) containing angular quartz and feldspar in a clay and limonitic matrix. Crossed nicols, X 40.

X-ray Spectrographic Analysis

Two uraniferous samples from each locality along with two nonuraniferous arkoses were analysed by X-ray spectrographic technique (Appendix B, p. 69).

All three prospects are characterized by minor amounts of uranium, arsenic, zinc, and in one case lead and copper. No lead or zinc minerals were identified; secondary uranium minerals account for the copper and arsenic. Iron, manganese, zirconium, and titanium are present in the uraniferous zones and the surrounding non-mineralized rock. No primary uranium minerals, nor sulfides, with the exception of pyrite, were identified. This is not unexpected because of the thoroughly oxidized condition of the ore.

URANIUM OCCURRENCES IN MISSISSIPPIAN ROCKS

Carbon County

Introduction

Uranium minerals were recognized from the Carbon County area as early as 1874. Wherry (1914) described the carnotite occurrence north of Jim Thorpe (Mauch Chunk) in the transitional beds between the Mississippian and Pennsylvania rock formations. Recently three additional occurrences in Upper Devonian beds were reported. Dyson (1954), Klemic and Baker (1954), and Montgomery (1954), have published reports on these occurrences. The following is a brief summary of their work along with the author's observations.

The uranium occurrences are in the tightly folded zone at the northeastern edge of the Southern Anthracite Basin. These folds end abruptly to the northeast in the relatively undeformed Pocono Plateau region. The occurrences (5, 6, 7, and 8, Appendix A) are in rocks that range in age from Upper Devonian through Upper Mississippian. They are characterized by the presence of secondary uranium vanadates, carbonates, and silicates along with a primary uraninite-like oxide and, at one locality, the lead selenide, clausthalite (PbSe).

Considerable exploration work was done in 1953 at the Mt. Pisgah occurrence. An extensive drilling program was conducted and three small test adits were driven for distances up to 50 feet into the cliff face exposing the mineralized zone. Some 300 tons of ore grade material taken from the test adits were delivered to the Atomic Energy Commission. Work was discontinued, however, because of the irregular distribution of the ore.

Stratigraphy

Part of the stratigraphic section reported in Klemic and Baker (1954, p. 2) is given below.

Table 2

Pennsylvanian	Thickness
Productive coal measures	975
Pottsville conglomerate	880
Mississippian	
Mauch Chunk shale	2170
Pocono sandstone	1255
Devonian	
Catskill red sands and shales	7145
Chemung and Portage shales and flags	1290

The Upper Devonian marine, Catskill, and Pocono formations are described with the Devonian occurrences.

The Mauch Chunk Formation at its type locality, Jim Thorpe (Mauch Chunk), consists of a series of red shales, sandstones, mudstones, and siltstones with some discontinuous gray to green units. It is a continental red bed formation similar in appearance and origin to the Catskill Formation. The problem of determining the top of the formation in this area is one of long standing. The change in conditions of sedimentation from red bed deposition to deposition of quartz conglomerates and tan to gray arenites was sporadic. Toward the top of the formation quartz pebble conglomerates and gray sandstones are overlain by red beds. The base of the overlying Pottsville Formation is usually taken at a rather persistent quartz conglomerate unit similar to the basal Pocono Formation. The problem is whether to place the base at the first conglomeratic horizon or at the highest red bed. Since the latter is done in the case of the transition between the Catskill and Pocono Formations and also represents a more easily mappable boundary, it is preferred. Therefore, the uranium bearing conglomeratic rocks at Mt. Pisgah are included within the Mauch Chunk Formation. This unit was formerly considered by Wherry (1914), Dyson (1954), and Klemic and Baker (1954) to be part of the basal Pottsville Formation.

The Pottsville Formation consists of coarse conglomerates, tan to gray sandstones with some black shales and thin coal beds higher in the sequence.

Mt. Pisgah (Prospect 5)

General description

The most significant uranium occurrence in the area is on the north flank of Mt. Pisgah. It lies close to the nose of a large southwest plunging syncline which is simple in form near the prospect but becomes increasingly complex to the southwest. The radioactive zone is exposed discontinuously

along U.S. Highway 209 for a distance of over 2,000 feet. The cliff face containing the ore zone was mapped by the writer (Fig. 4). The host rock is a dark-gray sandstone and conglomerate overlain by red beds. It is called the "U" member by Dyson, who subdivides it into three units. The top unit consists of dark-gray sandstones and siltstones overlain by red beds: Dyson indicates an average thickness of 21 feet but the unit is closer to 50 feet thick toward the eastern end of the exposure. The middle unit has an average thickness of about 45 feet and consists of conglomerate and coarse-grained dark-gray sandstone. Pebbles are mostly white quartz but shale and slate fragments are also common. The lower unit is a dark-gray sandstone and siltstone, of which only 6 to 10 feet are exposed.

From east to west along the outcrop the dip changes from 25° to 55°. The beds are cut by numerous shears, many of which are parallel to the bedding. Slickensides coated with secondary uranium minerals are common. Highly radioactive lenses of carbonaceous siltstone have been squeezed into irregular bodies along these fractures.

Petrology

Thin section studies indicate that the major constituents are: 1) angular quartz grains replaced along their margins by chlorite, 2) a sericite-chlorite matrix comprising about 20 to 30 percent of the rock volume, and 3) feldspar, both orthoclase and plagioclase, averaging about 10 percent of the total. Less abundant constituents include: 1) reddish-brown altered biotite, 2) calcite fracture fillings, 3) large muscovite flakes, and 4) the heavy detrital minerals, epidote, hornblende, zircon, tourmaline, and ilmenite. Grains of the following rocks were reported by Montgomery (1954): 1) schist, 2) limestone, 3) serpentine, 4) siltstone, 5) slate, and 6) shale. Heavy mineral separations made by the author also reveal a minor amount of pyrite. Previous workers have referred to the rocks as arkoses or sandstones. However, from the above information it seems clear that they might better be classified as graywackes or subgraywackes (Krumbein and Sloss, 1951, pp. 132-134).

Mineralogy

The following secondary uranium minerals were identified by previous workers on the basis of optical work and X-ray powder photographs:

1) schroeckingerite	$Na, Ca_3(UO_2)(CO_3)_3(SO_4)F. 10H_2O$
2) liebigite	$Ca_2U(CO_3)4. H_2O$
3) andersonsite	$Na_2 Ca(UO_2(CO_3)_3 6H_2O$
4) carnotite	$K_2(UO_2)_2(UO_4)_2 . 1\text{-}3H_2O$
5) tyuyamunite	$Ca(UO_2)_2(UO_4)_2 . 7\text{-}10\ ½H_2O$
6) uranophane & beta uranophane	$Ca(UO_2)_2Si_2O7 . 6H_2O$

In addition, Montgomery (1954) isolated and tentatively identified a uraninite-like primary oxide concentrated in carbonaceous zones of the chloritic-sericitic rock matrix. However, a major portion of the radioactivity is from areas which show no visible uranium mineralization. Here, the radioactivity is attributed to minute disseminated particles. Under magnifications of 1,100x Montgomery observed brightly reflecting spherical shapes within quartz and other transparent grains. These he believes to be finely divided uranium oxide deposited along minute fractures in quartz.

X-ray powder photographs of heavy concentrates, taken in the Trace Elements Laboratory of the U.S. Geological Survey, and by the writer at Columbia University, showed no lines characteristic of any uranium mineral at ordinary temperature. On heating to 900° C., Montgomery obtained the powder pattern of the compound U_3O_8. At this temperature, however, all uranium minerals are converted to U_3O_8.

Montgomery (1954, p. 105) suggests that the unknown mineral may be some form of the primary oxide, uraninite. Because of its extremely fine grain size and apparently amorphous character it might better be referred to as a "pitchblende-like" mineral. Further detailed mineralogic work is necessary to define it more precisely.

X-ray Spectrographic Analysis

X-ray spectrographic analysis (Appendix B, p. 70) reveals that uranium and vanadium are the prominent constituents of the ore at Mt. Pisgah. Lead and zinc are also present, but in very minor concentrations. A sample from the Penn Haven Junction occurrence (Devonian) contained no detectable vanadium but a considerably greater amount of lead along with a trace of zinc.

Huntingdon County

Location

Prospect 4 in Huntingdon County, south central Pennsylvania, is also in the Mauch Chunk Formation. It is at the base of Round Knob, a small outlier capped with Pottsville sandstone located on the east flank of the Broad Top Coal Basin (Fig. 5).

Stratigraphy and Structure

The Mauch Chunk Formation in this area consists of red shale, siltstone and sandstone, with some discontinuous gray to brown units. It contains a limited flora and plant fragments which are commonly found within its gray, unoxidized portions. In the vicinity of the Broad Top Basin it is somewhat less than 1,000 feet thick, and the uranium occurrence is about 500 feet from the top.

The sediments near the center of the syncline lie close to the horizontal whereas those on the flanks are sharply upturned. The basin is bordered on the west by the Henrietta thrust fault. The McConnellsburg thrust is about eight miles from its eastern limb.

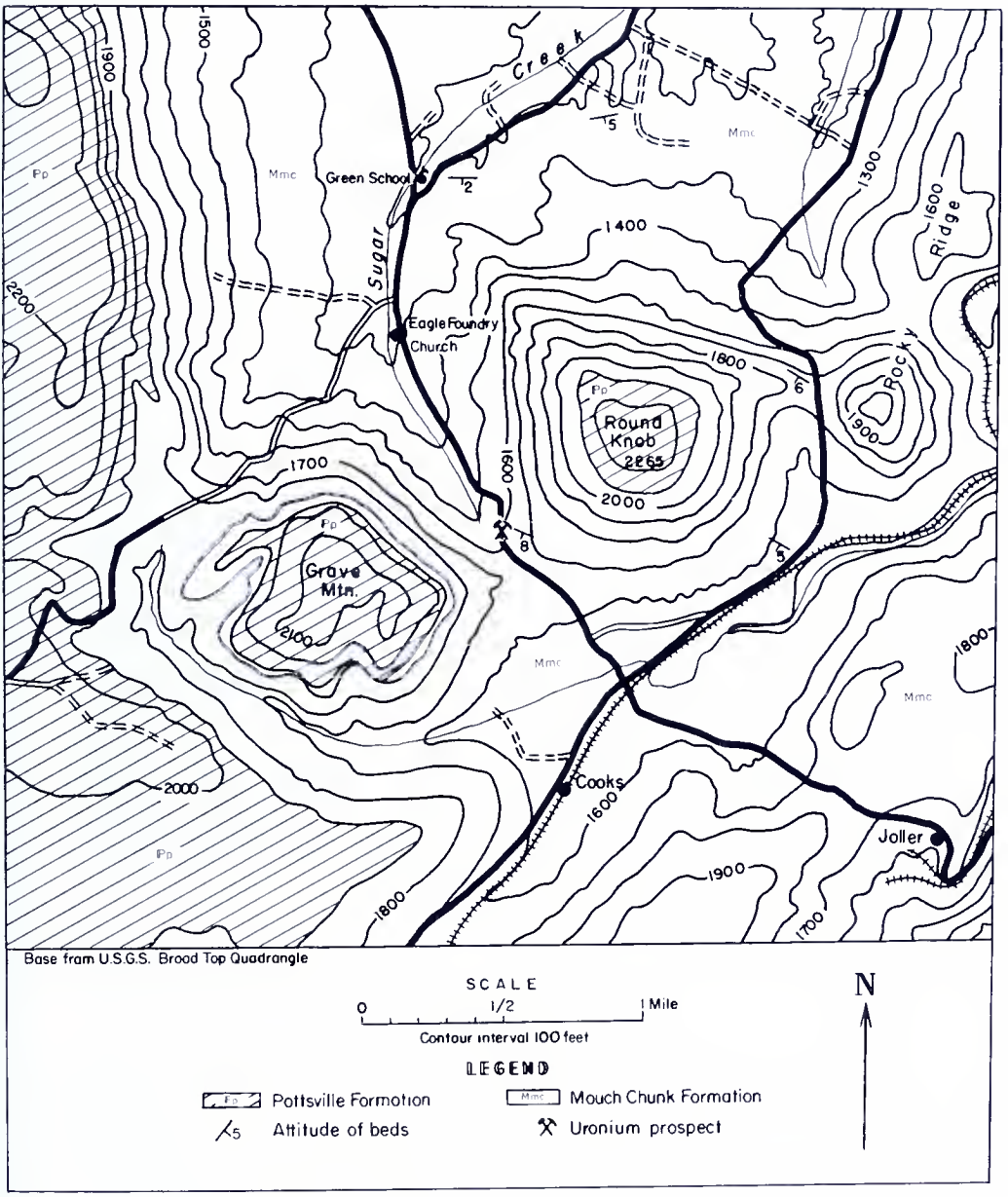


Figure 5. Geologic map of the Round Knob area.

The Broad Top occurrence is exposed for a distance of about 150 feet on the north side of Route 994, about 200 yards northwest of a small cemetery at the base of Round Knob. The sediments in the vicinity of the

occurrence have a fairly uniform dip to the south and lie close to the axis of the south plunging portion of the syncline. No faulting was noted in the vicinity but a pronounced set of rectangular joints has resulted in spheroidal weathering of the sandy units. Some of the mudstones are cut by sets of intersecting shears along which slickensides and pyrolusite coatings are seen.

Petrology and Mineralogy

Mineralization is restricted to composite lens of brown to gray sandstones, siltstones, and mudstones in red shale (Fig. 6). A number of small, elongate sand and siltstone lenses, some of which are radioactive, are interbedded with mudstone which makes up the major part of the depression. It is interpreted that the composite lens represents the incised portion of a paleostream channel.

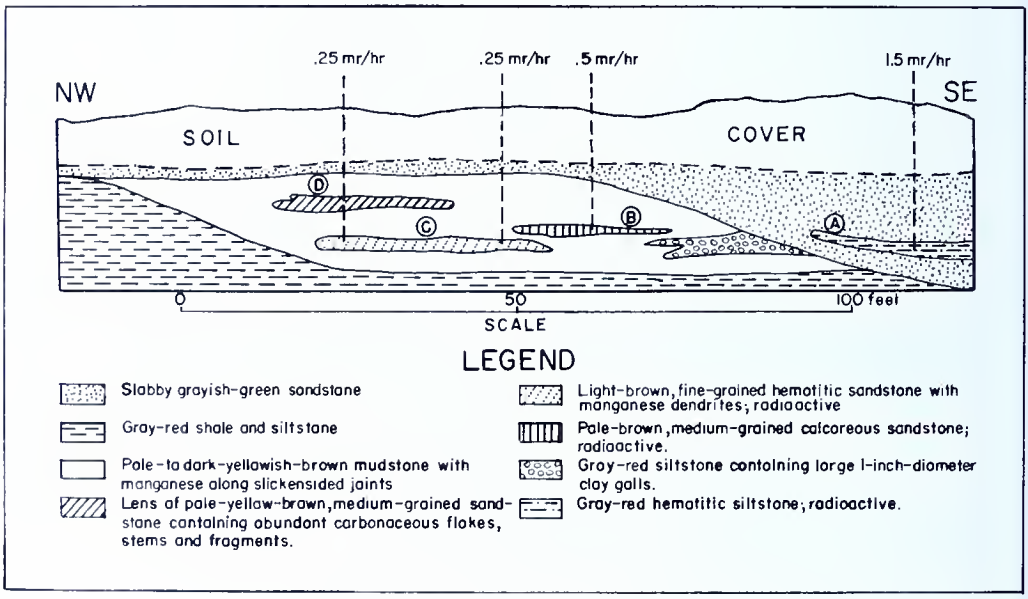


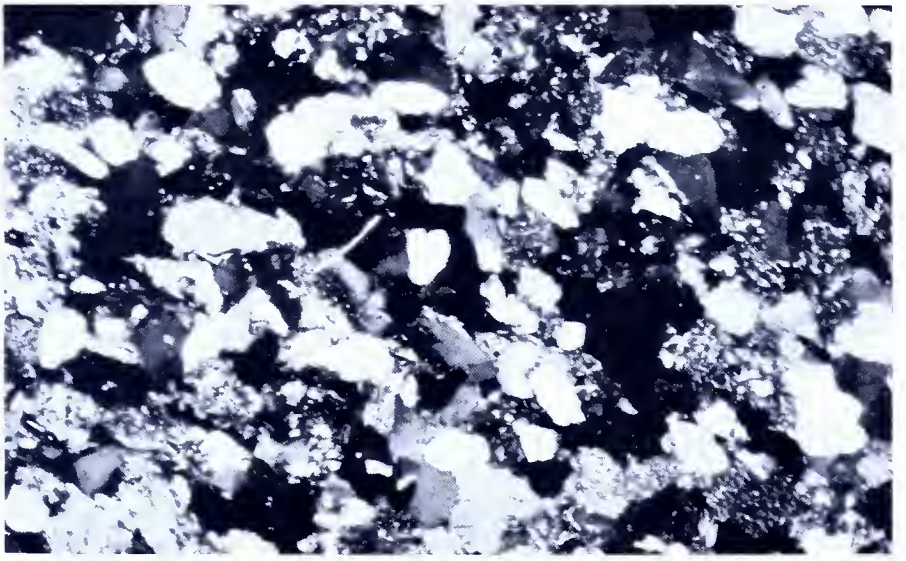
Figure 6. View of Round Knob occurrence.

Distribution of radioactivity is irregular, with the highest counts obtained from a grayish-red siltstone lens at the southeastern edge of the exposure (Fig. 6, A). The upper part of the channel is obscured by slumped soil, as is the southeast portion toward the cemetery. This unit is noteworthy because it represents the only red sediment within the state that displays significant radioactivity. It is composed of angular to subrounded quartz grains set in a nearly opaque matrix consisting of hematite and clay minerals. This matrix comprises 40 to 50 percent of the total volume. The quartz is locally replaced by chlorite and other clay minerals. Many of the

quartz fragments are elongate parallel to the bedding. Also present in abundant quantities is partially chloritized biotite. Chlorite, in addition to being an alteration product of biotite, occurs as an authigenic mineral. Muscovite is present, but in lesser quantity. Secondary uranium minerals were detected in thin section and heavy mineral analysis.

The pale-brown, medium-grained, calcareous sandstone "B" is similar to "A." It consists of subangular to subrounded quartz set in a clay, calcite, and iron oxide matrix. The percentage of matrix is about 20-25 percent. Chlorite occurs in the same manner as in "A." Altered biotite is abundant; muscovite considerably less so (Pl. 2).

Plate 2



Zone "B". Red-gray radioactive siltstone containing angular to subangular quartz, along with muscovite and biotite in a sericite-chlorite matrix. Crossed nicols, X 40.

The third radioactive lens ("C") is a light-brown, fine-grained hematitic sandstone containing manganese dendrites. The matrix comprising 60 percent of the volume consists chiefly of clay minerals and iron oxide. Fine-grained, subangular to subrounded quartz, together with a lesser amount of biotite and chlorite, are major constituents. Limonite or goethite appears to be the prominent iron mineral rather than hematite. This unit is similar to those already described except in grain size and percentage of matrix. Secondary uranium minerals are present in very minor amounts.

The nonradioactive yellow-brown, medium-grained sandstone ("D") contains abundant plant fragments, several inches in length. They are soft and sooty as a result of weathering. Smaller, fairly fresh, carbon flakes are present in thin section. No interstitial calcite is present and the clay matrix constitutes 40-50 percent.

All units are characterized by recrystallization of the quartz grains, minor amounts of feldspar in various stages of alteration, and accessory minerals such as zircon, and tourmaline.

Radiometric field assays made by the writer on two samples of unit "A" gave U_3O_8 equivalents of 0.15 percent and 0.25 percent. The major uranium mineral is carnotite, $K_2(UO_2)_2(UO_4)_2 \cdot 1\text{-}3H_2O$, identified from its X-ray powder pattern and confirmed by X-ray spectrographic analysis. It is in small, irregularly distributed masses throughout the three radioactive units. A few pale-yellow-green, tetragonal crystals were detected in heavy mineral separations. On the basis of their fluoresence they are tentatively identified as autunite or meta-autunite. The amount of material was insufficient for confirmation by X-ray methods. It is believed that the carnotite and other minerals were derived by weathering from a primary uranium mineral associated with carbonaceous material. The radioactivity of the red unit ("A") is partially due to minor amounts of secondary minerals; however, these are insufficient to account for all the radioactivity. The remainder may emanate from uranium absorbed by colloidal hydrous ferric oxide as at the Goodspring, Nevada occurrence (Barton and Behre, 1954).

No primary uraninite or pitchblende was identified in any of the uranium bearing units nor would it be expected at shallow depth in permeable sediments, because of its lack of stability under oxidizing conditions. Even in places where sulfides such as chalcopyrite and bornite are preserved, uranium commonly is in the form of secondary oxides.

The least weathered unit ("B") contained minor amounts of the following minerals: chalcocite, chalcopyrite, pyrite, and malachite. The chalcocite identification was confirmed by X-ray powder photograph, the others were identified by binocular miscroscope. The paragenesis of these minerals can only be inferred, since they were not observed in thin section nor in the cut surfaces of samples. It is believed that they are associated with the carbonaceous material.

X-ray Spectrographic Analysis

X-ray spectrographic analysis of selected samples revealed the presence of uranium, copper, lead, zinc, manganese, and arsenic, along with the common constituents of sediments of this type: iron, zirconium, and titanium (Appendix B, p. 70).

URANIUM OCCURRENCES IN DEVONIAN ROCKS

Introduction

The majority of the uranium occurrences in Devonian rocks are in the relatively undeformed region near the Allegheny Front, in Lycoming, Sullivan, Bradford, Wyoming, and Columbia counties (Fig. 7). The remainder are localized in the intensely deformed Ridge and Valley area of Huntingdon, Northumberland, Carbon, Lackawanna and Wayne counties. The host rocks are lenses of gray to green sandstones intercalated with red beds of the continental Catskill Formation. Mineralization is closely associated with plant fragments. Copper and lead sulfides replace the carbonaceous material. Secondary copper and uranium minerals occur as encrustations along bedding planes.

The occurrences are small, with mineralization usually confined to thin seams an inch or less in thickness with a lateral extent of only a few feet. Several larger occurrences were examined but even these are not presently economic.

The copper deposits in the Catskill Formation were periodically worked during the latter part of the 19th century. Many of the occurrences represent old copper workings in which interest has been renewed because of their associated radioactivity. In referring to an occurrence in Nicholson Township, Wyoming County, I. C. White reported (1883, p. 129):

> "Slight traces of copper, lead, and nickel and sometimes zinc, are found in the Catskill rocks very frequently; but always in such minute quantities that mining can never be profitable. . . ."

Weed (1911) mentioned that copper occurrences of this type were known as early as 1850, particularly in the region near New Albany where the Carpenter Mine, Prospect 34, was worked about the year 1854. He also reports numerous deposits of this type in Monroe and Pike counties in northeastern Pennsylvania. J. P. Lesley (1892, p. 1572) reported that copper is commonly found in small quantities at the base of what was thought to be the Honesdale Sandstone in northeastern Pennsylvania.

Stratigraphy

Catskill Formation

The Catskill Formation consists of a sequence of predominantly red sandstones, siltstones, shales, and mudstones. Gray to green sandstones and shales make up approximately 25 percent of the total thickness. The formation is best developed in the eastern part of the state in the main folded belt of the Appalachians (Perry, Dauphin, Schuylkill, and Carbon counties).

Deposition was predominantly deltaic in the east, but conditions changed to estuarine and marine to the west. A continental offlap situation exists so that the lowest deltaic beds (red siltstones) in the east are older than their counterparts to the west. The contact between the Catskill Formation and the underlying marine beds is transitional. Cross-bedded, red siltstones which are continental in origin alternate with brown, fossiliferous, evenly bedded, marine sandstones and shales.

I. C. White (1881, 1885), contributed most of the original work on the stratigraphy of the Catskill Formation. He attempted to subdivide the formation into various mappable units.

These units were recognized by White in the northeastern part of the state and some attempt was made to carry them to other areas. However, he clearly recognized the difficulty of correlation and stated (1883, p. 55):

> "The rocks of this series prove so variable when traced southward through the region that it was found impossible to keep hold of all the subdivisions that were established for Wayne and Susquehanna counties in 1880. . . .
>
> "The character of the rocks, however, is very changeable; since in one section more than two-thirds of the whole series may be massive-looking, greenish sandstones, with only thin beds of red shale interstratified; while only a few miles distant the green sandstones disappear and in their stead are found very thick red beds."

Willard (1939) revised and expanded White's work on the Catskill using the same general subdivisions with some redefinition, especially of the lowest units.

In summary, it may be said that the subdivisions of the Catskill Formation originally made by I. C. White and elaborated upon by Willard are not units that can be recognized easily, even in the type area, to say nothing of the regions to the west and south into which Willard attempted to extend them. As mappable units the subdivisions are inadequate except on a very local scale.

The lowest red bed was used by the author in mapping the North Mountain area, where a large number of occurrences are localized (Fig. 7). It was particularly useful since the uranium occurrences are found only in continental rocks. If the first occurrence of fossils were used, a considerable thickness of continental red beds would be mapped with the underlying marine formation. It seemed practical to map as one unit all the beds in which uranium mineralization is likely to occur.

The Catskill Formation can be subdivided in the area where most of the uranium occurrences are concentrated (northern Columbia and north-

western Lycoming counties). Six fairly distinct rock units have been recognized but no correlation has been made with the subdivisions described by Willard (1939) because of the previously mentioned lateral variability of the formation and the lack of precision in the definition of these subdivisions.

1) Red shale about 50 feet thick.
2) Coarse-grained, green sandstone, 400-550 feet thick, interbedded with red shales.
3) Red shale and mudstone interbedded with minor amounts of gray sandstone, 1,000 feet thick.
4) Gray to green channel deposits intercalated with red sandstones and shales, 200-300 feet thick. The majority of the uranium occurrences are localized in this part of the formation.
5) Red shale and mudstone, also 200-300 feet thick.
6) Transitional zone in which red and green sands and silts alternate with brown to buff marine sands and shales, about 1,000 feet thick.

The distinction between the three lowest units is difficult where exposures are poor. Therefore, in places they are grouped together into an undifferentiated unit, referred to as the lower Catskill Formation.

Pocono Formation

The Pocono Formation which directly overlies the Catskill, consists of massive gray sandstone and conglomerate, which is thickest in Second Mountain from the Lehigh to Susquehanna rivers, thinning and becoming finer grained to the north and northwest. It is continental, contains a varied flora and some thin coal beds, and resembles the underlying greenish to gray sands of the upper Catskill Formation. A large portion of the Pocono Plateau is shown on the 1931 state map of Pennsylvania as Pocono sandstone although it is in reality upper Catskill sandstone. This error was pointed out by Willard (1939). The contact between the Catskill-Pocono Formations is apparently disconformable over much of the state, particularly in the west.

Marine Devonian

The rocks underlying the Catskill Formation in the area studied consist of alternating brown to buff, even-bedded, sandy shales, formerly called the Chemung Formation and now simply designated as Upper Devonian Marine.

Stratigraphic Control

The stratigraphy of the Catskill Formation was given considerable attention in order to obtain an understanding of the stratigraphic distribution of the uranium occurrences. It was established that Willard's (1939) subdivisions are inadequate as marker beds. The only consistent marker to which the various occurrences could be related was the base of the Pocono Formation.

Individual occurrences have no horizontal continuity. The mineralized zones and the surrounding gray to green sands tend to pinch out or grade laterally into red sands or shales. The uranium zones occur within a complex overlapping network of carbon-rich sand lenses. Prospects tend to be localized in clusters as in the vicinity of New Albany, Beaver Lake, and Central. This uneven distribution may be real or apparent, simply reflecting insufficient prospecting. However, clustering of occurrences is common in the similar deposits of the Colorado Plateau.

Within a single cluster the occurrences tend to appear at varying stratigraphic positions as seen on the cross sections (Fig. 8) and on the isometric projection of the stratigraphic locations (Fig. 9). It is apparent that the majority of the occurrences have certain preferred stratigraphic positions as measured from the base of the Pocono Formation; at New Albany and Beaver Lake they are from 2,000 to 2,500 feet below it. The Catskill Formation is about 3,000 to 3,500 feet thick near Beaver Lake and Central, and about 2,500 feet thick near New Albany. Thus, the New Albany occurrences and prospects 22 and 23 to the west of Beaver Lake lie near the base of the formation.

Structure

The Devonian copper uranium occurrences are found in three general structural environments: the folded belt, the plateau, and the intermediate area. The Appalachian folded belt contains three prospects, Mauch Chunk Ridge (Prospect 6), Herndon (Prospect 41), and Orangeville (Prospect 40). The beds at these localities range in dip from 26° at Orangeville to 45° at Herndon near the middle of the belt to 77° at Mauch Chunk Ridge near its eastern edge. This is consistent with the general increase in the intensity of deformation from northwest to southeast (Fig. 10).

The great majority of the occurrences are in what might be termed a border zone between the main folded belt and the more gently deformed Allegheny and Pocono Plateaus. The tight Appalachian folds die out rapidly across this border zone and within a few miles pass into broad open structures. Dips in uraniferous zones average from 8° to 15°. The largest

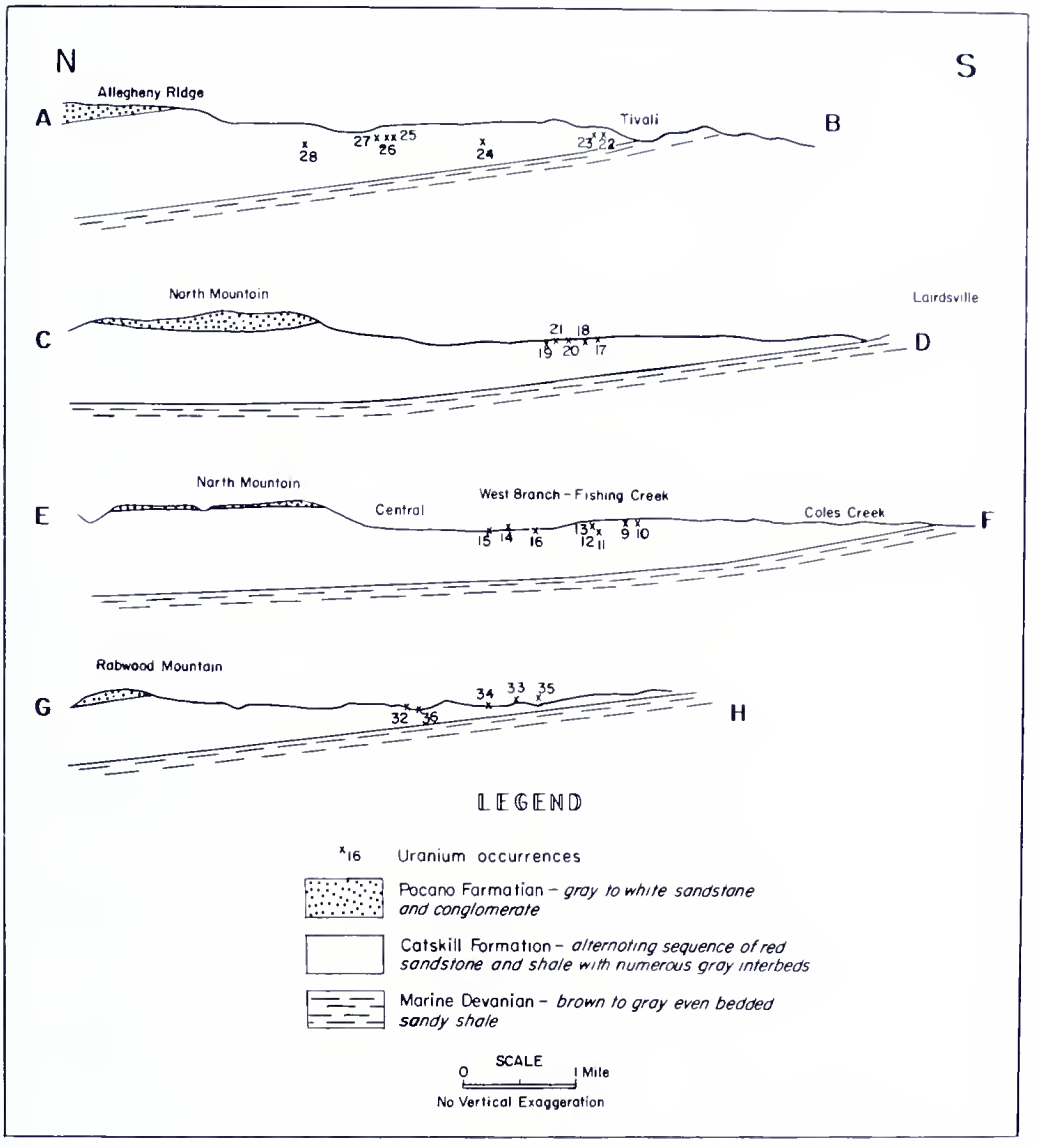


Figure 8. Geologic cross sections.
Line of sections shown in Figure 7.

number of occurrences (25) are concentrated on the south flank and tip of North Mountain (Noxen syncline) which constitutes the Allegheny topographic front in Columbia, Sullivan, and Lycoming counties. Prospects 7 and 8 in Carbon County and 38 and 39 in Wayne and Lackawanna counties are located in the border zone between the fold belt and the Pocono Plateau.

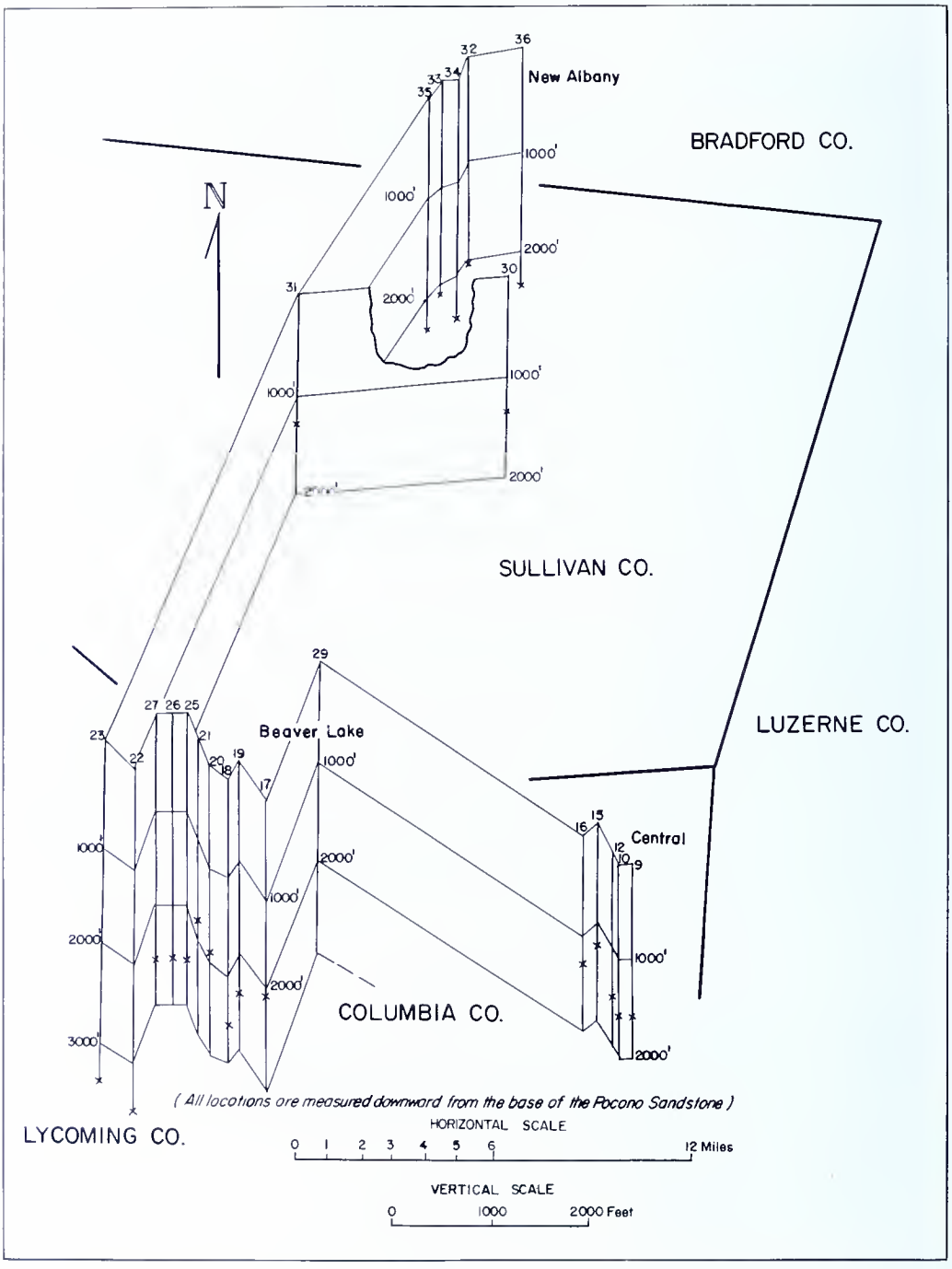


Figure 9. Isometric diagram of the stratigraphic positions of the Devonian occurrences.

The remainder are well within the Allegheny Plateau on the flanks of the Wilmot anticline, near the town of New Albany in Bradford County. Here, dips are usually less than 5° although exceptions are noted at the nose of the anticline near the Forksville occurrence (Prospect 30). In general, the surface of the plateau is characterized by relatively simple, open structures. However, to the west of the area under discussion the intensity of the folding increases markedly at depth (Fettke, 1954, p. 8). Very tight subsurface folds, and faults with displacements up to a thousand feet have been reported. Little subsurface data is available in Bradford and Sullivan counties but it may be assumed that the subsurface situation is not too dissimilar to that of the counties 30 to 50 miles to the west and along strike of the major structures.

Structural Control

The strata immediately surrounding the occurrences are cut by joints intersecting at angles which range from 45° to 90°. These do not appear to exercise any primary control on the mineralization. The fracture surfaces do not exhibit any significant mineralization, except minor amounts of malachite, azurite, pyrolusite, and in rare cases, secondary uranium minerals. In most cases the fractures are remarkably tight so that secondary oxidation products tend to migrate into the surrounding shales and sandstones along bedding planes rather than along fractures. These structural features, therefore, do not appear to be important in localizing the mineralization.

Description of Significant Occurrences

Since approximately forty prospects are now known in the Catskill Formation, no attempt at a complete description of each will be made in the text of this report. However, a complete list, along with locations and descriptions of each prospect studied is given in Appendix A. Many of the occurrences are small and some consist of no more than a few mineralized plant fragments. They are distributed in clusters centered about the New Albany area, the Beaver Lake area, and the Central area.

General Characteristics of Mineralized Zones

The mineralized zones are restricted to the carbon-rich, gray to green portions of paleostream channels. Some of the carbonaceous material is in the form of recognizable plant fragments localized in thin seams and stringers, rarely more than 1 inch thick. In addition to the seams, macerated fragments ranging from 6 inches in length down to microscopic size are present. The uranium minerals are closely associated with the carbonaceous material. Their exact relationships are described on a later page.

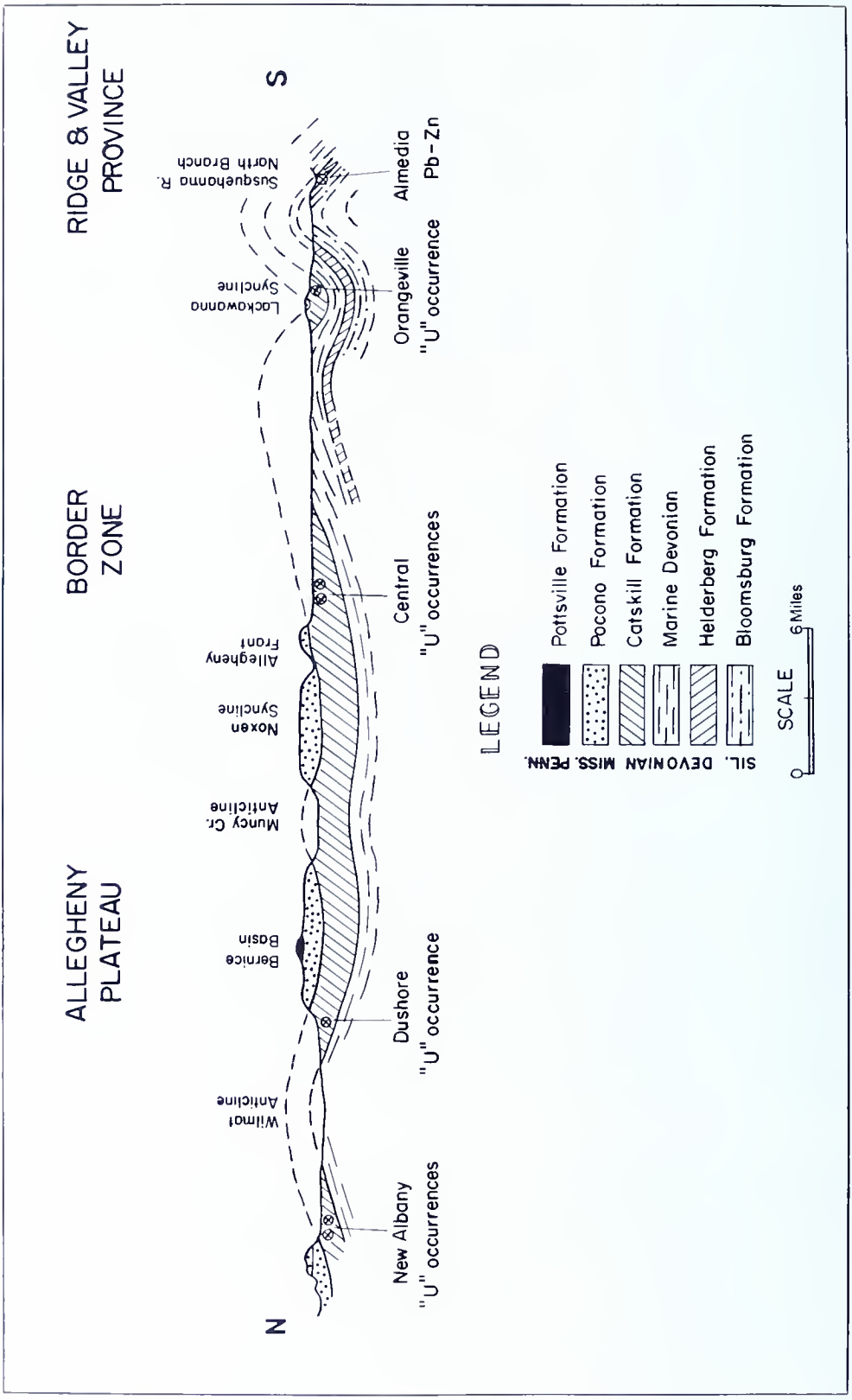


Figure 10. Geologic cross section from Almedia to New Albany.

In many places fresh carbonaceous material can be obtained only a few feet down dip from the outcrop. This material is hard, jet black and has a vitreous luster. It shows a well developed set of joints but sometimes breaks with a conchoidal fracture. This coaly material was identified as vitrain. However, it also contains bands of sooty fusain in which original plant textures can be recognized.

A small quantity of carbonaceous material from prospect 12 was separated from the surrounding shales and analysed. The results are given in Table 3 and compared with analyses of other coals from various regions of Pennsylvania as reported by Lord (1913).

Table 3

	Carbonaceous Material[1]	*Bernice Basin Sullivan Co. (semi-anthracite)*[2]	*Gossam Mine Clearfield Co. (semi-bituminous)*[2]	*Homer City Indiana Co. (bituminous)*[2]
Moisture	5.73%	3.38%	1.9%	2.98%
Volatile Matter	22.09%	8.47%	23.0%	27.38%
Fixed Carbon	58.75%	76.65%	68.9%	60.44%
Ash	13.43%	11.50%	6.2%	9.20%

[1] Analysis by A. S. McCreath and Son, Harrisburg, Pa.
[2] Analysis from Lord, U.S. Bureau Mines, Bull. 22, 1913, (pp. 166, 169, 180)

The material is not lignite as reported from the red bed deposits of the southwest, but is close to bituminous coal in rank. It differs in volatile material and fixed carbon from the coal of the Bernice Basin only 12 miles to the north. It is noteworthy that this Devonian material is lower in rank than the younger Pennsylvanian coal. One explanation may be that the Devonian material originally had a higher volatile content which might have been an important factor in localizing the mineralization. The only previous attempt to identify this type of material was made by Butler (1938), who reported a volatile content of 13.5 percent and that the material is non-coking, and either semi-bituminous or anthracite in rank.

The mineralized areas are marked by malachite, less abundant azurite, and minor concentrations of secondary uranium minerals. All occur as thin films and encrustations along the bedding planes.

The local gray or greenish zones do not represent stream channels in their entirety, but rather are zones where carbonaceous material is particularly abundant. Individual sand lenses, incised into red shales and mudstones, change color laterally from gray and green hues to grayish red away from the carbonaceous areas.

Some parts of the section contain a greater abundance of coarse gray to green sands than do others. These portions of the section may originate with rejuvenation of the source area, resulting in an increased number of faster flowing streams and more rapid and efficient burial of carbonaceous material. The predominantly shaly portions represent deposits of sluggish streams flowing from an essentially stable and deeply eroded highland area.

The mineralized stringers or seams are rarely more than an inch in thickness, although there may be several in one zone. They continue laterally along an outcrop for only a few feet. Meager drill information indicates that they are not extensive in the third dimension. Thus, mineralization is confined to thin planar bodies conformable with the enclosing sediments. These bodies pinch out in all directions within a few tens of feet. The thickest mineralized seam (Prospect 12) contained several parallel stringers within a zone about one foot thick. The surrounding host rock is permeated with malachite. This zone could not be traced more than 30 feet along strike or more than 10 to 15 feet down the dip.

Mineralization is noted in both the sandy and the shaly portions of the stream channels. However, it is found most commonly at the base of sand lenses incised into shales or mudstones. Carbonaceous material tends to be preserved at these disconformable boundaries because of rapid burial after channel scouring.

Uranium and visible sulfide mineralization are not everywhere coincident. However, radioactivity usually is highest in sulfide-rich zones, although exceptions exist. In some places soft, weathered, carbonaceous material exhibited radioactivity attributable to adsorbed uranium probably leached and redistributed by ground water during the present erosion cycle. Although copper, lead, and zinc minerals cannot always be identified from individual samples, X-ray spectrographic analysis (Appendix B) indicates these elements are present in variable quantities in all the Pennsylvania uranium occurrences.

Lenses of limy sandstone (calcarenite), containing large shale pellets, are one of the most consistent features of the ore zones. Such lenses occur in varying relationships to the ore, sometimes above, other times below it. They weather dark brown, are pitted, cavernous, and often recessed from the outcrop. The deeply weathered material is soft and friable. These lenses are rarely mineralized so that no positive genetic implications can be drawn from their presence.

Petrology

Twenty-eight thin sections from the uraniferous zones and the surrounding country rock were studied. The rocks are classified as subgraywackes on the basis of the following modal averages of the major constituents: 1)

Quartz, angular to subangular 40 to 50 percent, 2) matrix of fine-grained chlorite and muscovite 30 to 40 percent, 3) Interstitial hematite 10 to 20 percent. The minor components which make up from 5 to 10 percent of the total are, in approximate order of abundance: large muscovite flakes, magnetite, feldspar, zircon and interstitial calcite (Pl. 3).

The matrix is composed of chloritized muscovite along with illite and kaolinite. Authigenic chlorite along quartz grain boundaries is also present. Interstitial hematite, the coloring agent in the reddish rocks, is almost completely absent in the gray to green subgraywakes. The coloring agent in these units is the chlorite, which ranges from 14 to 21 percent of the total. The percentage is about the same both in the red and green sediments.

The total amount of matrix is higher near the mineralized zones than it is 6 to 20 feet away. A matrix of about 40 percent is common in samples taken near the mineralization while 30 percent is the average for those from the marginal areas. Thus, the sorting in the uraniferous zones is poorer than in the country rock.

Quartz recrystallization is more pronounced in these more poorly sorted sediments. The grains in the country rock are discrete angular to subangular particles while those near the mineralization are welded together, forming larger, extremely irregular aggregates.

The limy sandstone commonly associated with the mineralization, consists of angular quartz and large muscovite flakes in a calcite and clay matrix. Flattened clay galls which range up to two inches in length are also present. Carbonaceous material is commonly found within these lenses, in which case they sometimes exhibit mineralization.

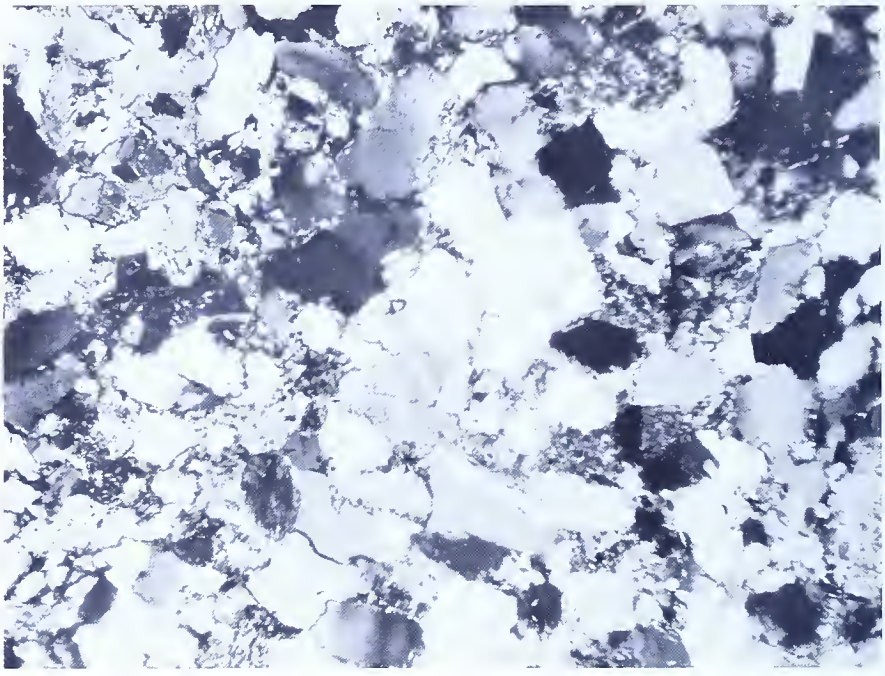
These calcarenites are either red or gray, depending on whether or not interstitial hematite is present. It is interesting to note that in the gray calcarenites the clay galls are in many instances red, indicating that the sediments from which they were derived were red prior to erosion and redeposition. Such red clay galls are commonly altered along the margins to a gray or green color, a secondary change brought about by reduction and redistribution of the iron.

Mineralogy

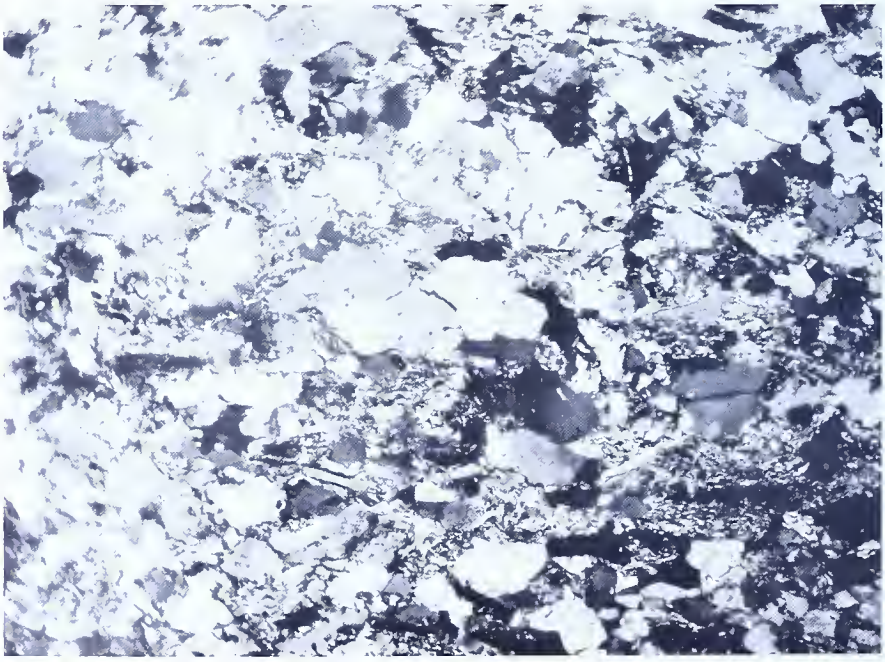
The minerals identified from the ore zones of the various prospects are given in Table 4.

The majority of the ore minerals were identified in polished section. In some cases these identifications were verified by X-ray powder photographs. The pyrite was examined by X-ray diffraction methods because much of the material in polished section displayed anomalous birefringence. It was previously misidentified as marcasite (McCauley, 1957). Galena was identified by X-ray methods because of the reported presence of claus-

Plate 3



A. Red subgraywacke 20 feet from ore zone at Prospect 31 containing angular to subangular quartz grains in a matrix of hematite and clay. The quartz shows little evidence of recrystallization. Crossed nicols, X 67.



B. Gray subgraywacke from the ore zone at Prospect 31. This contains angular to subangular quartz which shows increased recrystallization; present also is a more abundant matrix consisting of sericite and clay. Crossed nicols, X 67.

thalite (PbSe), also isometric and silvery gray in color, at the Penn Haven Junction occurrence. The presence of both blue and white chalcocite-like minerals led to an X-ray investigation of both types. The bluish mineral proved to be digenite (Cu_9S_5) (Appendix B, p. 71), while the gray mineral was identified as chalcocite.

Table 4

Method of Identification

Mineral	*Binocular Microscope*	*Petrographic Microscope*	*Polished Section Microscope*	*X-ray Methods*
Pyrite	X		X	X
Bornite	X		X	
Chalcopyrite			X	
Galena	X		X	X
Digenite			X	X
Chalcocite	X		X	X
Covellite			X	
Barite	X	X		
Malachite	X			X
Chrysocolla	X			
Azurite	X			X
Uranophane				X
Metazeunerite	X			X
Uranospinite	X			X

Uranophane ($Ca(UO_2)_2(SiO_3)_2(OH)_2 \cdot 5H_2O$), was identified by powder X-ray methods by Dr. Lapham from a radioactive yellow-green efflorescence near one of the mineralized zones. The sample also contained metazeunerite, malachite, and quartz.

Metazeunerite and uranospinite were identified by the writer from X-ray powder photographs. A minor amount of metatorbernite is also present. The X-ray patterns of metatorbernite and metazeunerite correspond very closely, as pointed out by Frondel (1956, p. 121). A confirmatory test for the presence of arsenic was made by X-ray spectrographic analysis. These minerals are in the "meta" or dry state. This is not the situation expected under the relatively humid weathering conditions of the eastern United States. Frondel (1956, p. 120) points out that these minerals readily lose their water of hydration when subjected to warm, dry conditions. The specimens were stored in the laboratory for over three months before analysis during which time they may have lost this water of hydration.

Eight samples, four from the mineralized areas, and four from the host

rocks were studied to determine what differences, if any, existed in the clay mineral content. Standard clay mineral preparation techniques were used before X-ray diffractometer analysis (Table 5).

The mineralized zones and the host rocks as well as the gray and red units all contain the same suite of clay minerals. However, thin section study indicates that the overall clay mineral content is greater within the gray and green units in the vicinity of the mineralized zones.

Table 5

Clay Mineral Analysis

1	2	3	4
Gray sandstone Ore Zone Prospect 19	Gray shale Ore Zone Prospect 34	Gray sandstone Ore Zone Prospect 23	Gray shale Ore Zone Prospect 12
———	kaolinite	kaolinite	kaolinite
illite	illite	illite	illite
chlorite	———	———	chlorite
5	**6**	**7**	**8**
Gray sandstone Non ore Prospect 30	Red sandstone Non ore Prospect 30	Gray shale Non ore Prospect 9	Red shale Non ore Prospect 9
kaolinite	kaolinite	kaolinite	kaolinite
illite	illite	illite	illite
chlorite	chlorite	chlorite	chlorite

Polished Section Studies

In polished section, vitrain and fusain can be distinguished. Vitrain occurs in bands of uniform composition, is grayish tan, anisotropic, and exhibits almost parallel extinction. Adjacent to the vitrain are bands of sulfides (Pl. 4) which contain plant cell structures. In some cases the sulfides occupy the interior of cells, with rims consisting of carbonaceous material; however, in other areas no relict carbon is present and cell borders are composed of later sulfides. Thus, in addition to open space filling, replacement must be a factor in their preservation. The cellular areas are inferred to have originally contained fusain, or mineral charcoal. Although the precise origin of fusain is still open to question, it is known to commonly preserve the cell structures of plant material, whereas the other coal constituents do not.

In many cases the vitrain exhibits a well developed set of regular frac-

tures, interpreted as joints or cleats, in addition to numerous irregular fractures not related to any pattern. The vitrain is replaced by sulfides along these fractures and in some areas replacement has been so extensive that only disconnected shreds of the original material remain.

The fact that the sulfides are present in joints or cleats and other irregular fractures in the coal indicates that mineralization was not syngenetic. The carbonaceous material had progressed, at least, through the early stages of coalification before mineralization began. This point was also stressed by Butler (1938) in a study of several Devonian red bed copper occurrences in Wyoming County. However, the time and the depth of burial necessary for coalification are not known. Moore (1940, pp. 175-176) indicates that only a short period may be needed.

The ore minerals seen in polished section are pyrite, bornite, chalcopyrite, galena, digenite, chalcocite, and covellite. Also present are barite and quartz, along with secondary copper and uranium minerals. Two general associations were noted. The first consists of pyrite, bornite, chalcopyrite, galena, and digenite with minor secondary chalcocite and covellite. This type is found in the vicinity of Central, on the south flank of the Noxen syncline and at an isolated occurrence near Herndon. The second association, by far the more common, consists of pyrite, digenite, chalcocite, and covellite. It is found in the occurrences near New Albany, Beaver Lake, and in parts of several of the occurrences of the first type.

Quartz is the earliest mineral in the first sequence. It occurs as well formed crystals with hexagonal cross sections. It is followed by isolated irregular blebs of pyrite, a relatively minor constituent. Bornite and chalcopyrite are next in the sequence. The bornite occupies cell lumens within fusain bands and also occurs as irregular masses and fracture fillings in the homogeneous vitrain. The chalcopyrite occurs in fine laths oriented parallel to the (111) direction of bornite. This latticework within the bornite is readily seen only at magnifications of about 500 X. It is interpreted to be the result of exsolution of chalcopyrite from bornite. The most significant criterion is that the laths contract where they intersect rather than expanding as would be expected if they were a replacement feature (Schwartz, 1931, pp. 761-763). The presence of unmixing textures usually indicates that mineralization took place at elevated temperatures. Experiments conducted in an attempt to determine the minimum temperature of formation are discussed under a separate heading. Galena is later than the bornite-chalcopyrite intergrowth. In many areas it replaces bornite cell fillings from the center outward.

Digenite (Cu_9S_5), with a pronounced bluish cast, is generally later than the galena but the relationship is reversed in some places. This isometric mineral which closely resembles chalcocite in physical characteristics

(Buerger, 1941) formerly was called blue chalcocite, and it has been reported in red bed occurrences by Butler (1938) and Papenfus (1931). The best known digenite occurrence is at Kennecott, Alaska, where it is associated with chalcocite, covellite, and very minor amounts of bornite, enargite, luzonite, chalcopyrite, tennantite, sphalerite, and galena. The chalcocite and covellite at Kennecott show an unmixing texture generally interpreted as indicative of an elevated temperature of formation.

Barite, the next mineral in the sequence, fills fractures in the vitrain, and replaces pre-existing sulfides. Locally it occurs as radiating sheaf-like masses indicative of open space filling. Minute blebs of a later second generation of chalcopyrite are present within the barite. The last minerals are chalcocite and covellite, which occur in relatively minor amounts and may be the result of supergene enrichment.

Pyrite, the earliest mineral in the second assemblage, is somewhat more abundant than in the first. It fills cell cavities and is surrounded and replaced by chalcocite, here the most abundant mineral. The chalcocite also fills interstices in the surrounding sandstones and locally replaces quartz. Digenite and chalcocite are difficult to distinguish in polished section, so that their exact relationship is obscure. Faint lamellae, which might be the result of unmixing, were observed in some areas. Covellite is later than the digenite-chalcocite. Barite is the last mineral in the sequence.

Although chalcocite is the major mineral in this assemblage, the greater percentage of pyrite and the suggestion of digenite-chalcocite exsolution lamellae seem to rule out the possibility that chalcocite was derived from the first assemblage by supergene enrichment.

The paragenetic sequences for the two types are:

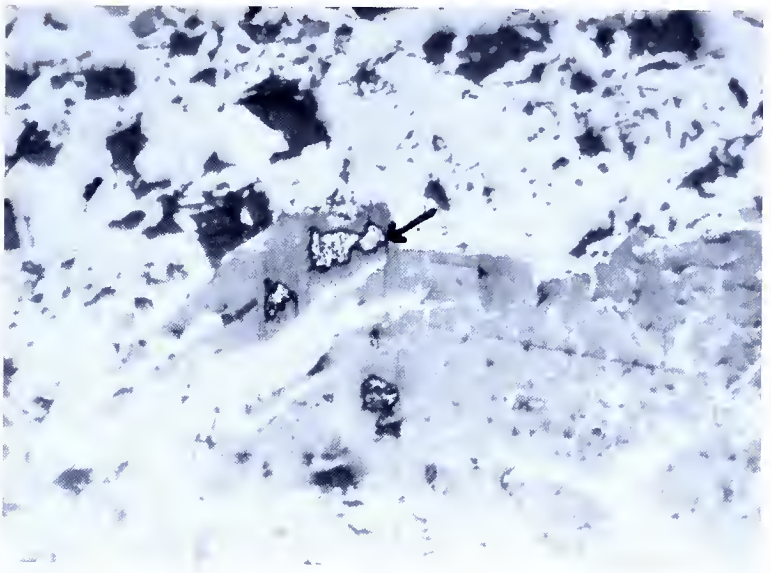
Type 1

Quartz	----
Pyrite	----
Bornite	----
Chalcopyrite	----
Galena	----
Digenite	----
Barite	----
Chalcopyrite	----
Chalcocite	----
Covellite	----

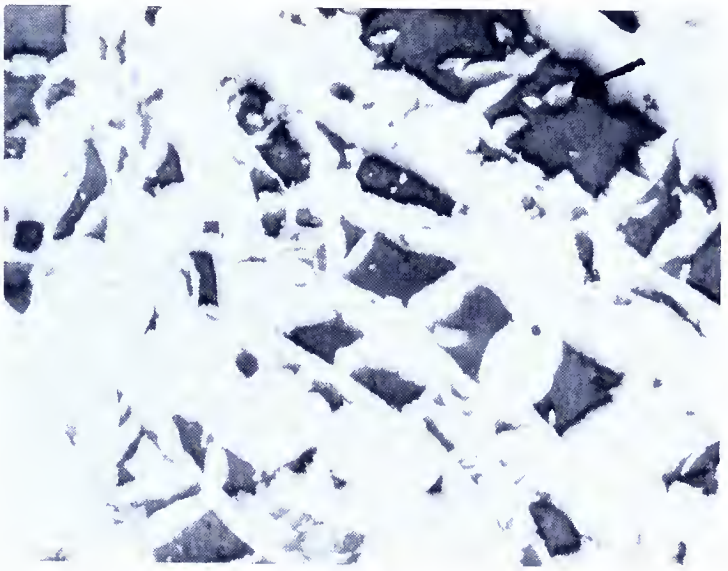
Type 2

Pyrite	----
Digenite	----
Chalcocite	----
Barite	----

Plate 4

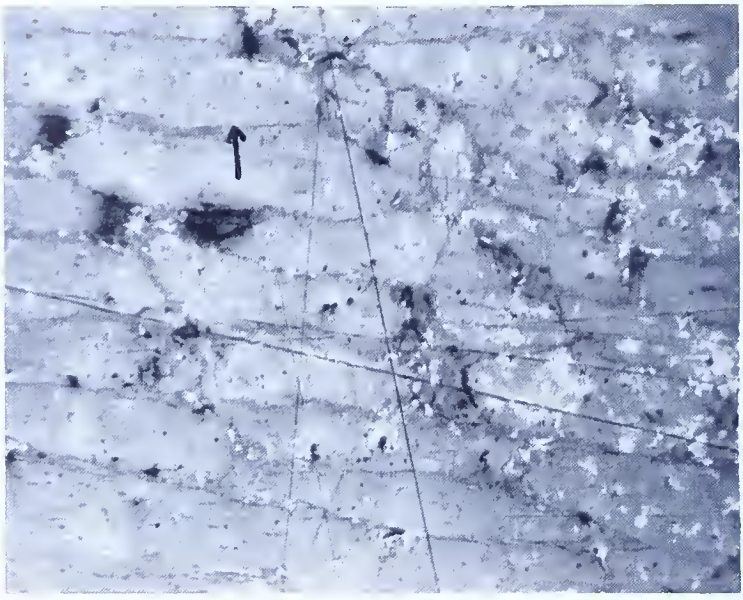


A. Small isolated remnants of pyrite (arrow) replaced by bornite (dark gray) which is replaced by galena (light gray). Black areas are gangue. Reflected light, X 180, Prospect 12.

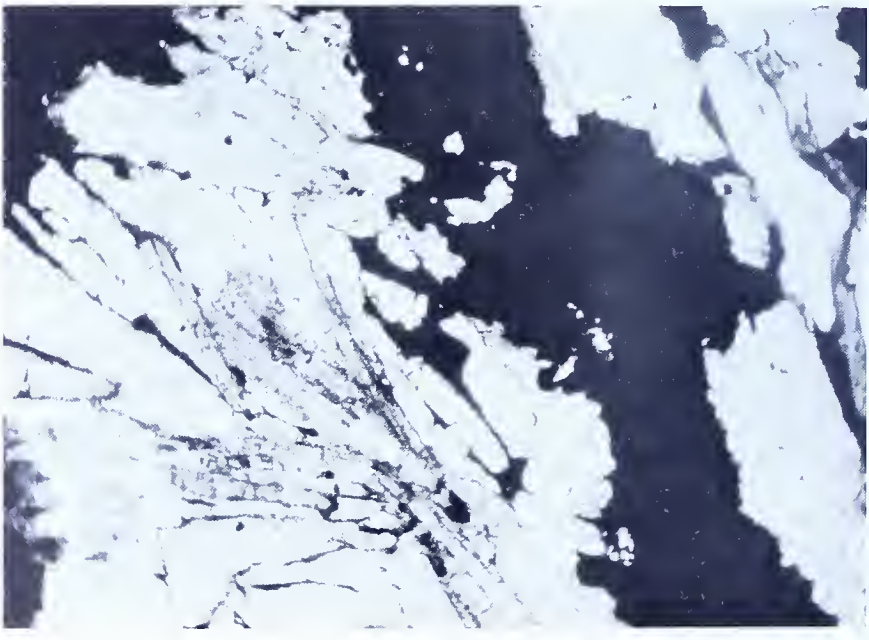


B. Carbonaceous material (vitrain) replaced by galena (light gray) with only shreds of the original material remaining. Cavities (arrow) are interpreted as resin blebs filled by sulfides. Reflected light, X 180, Prospect 12.

Plate 5

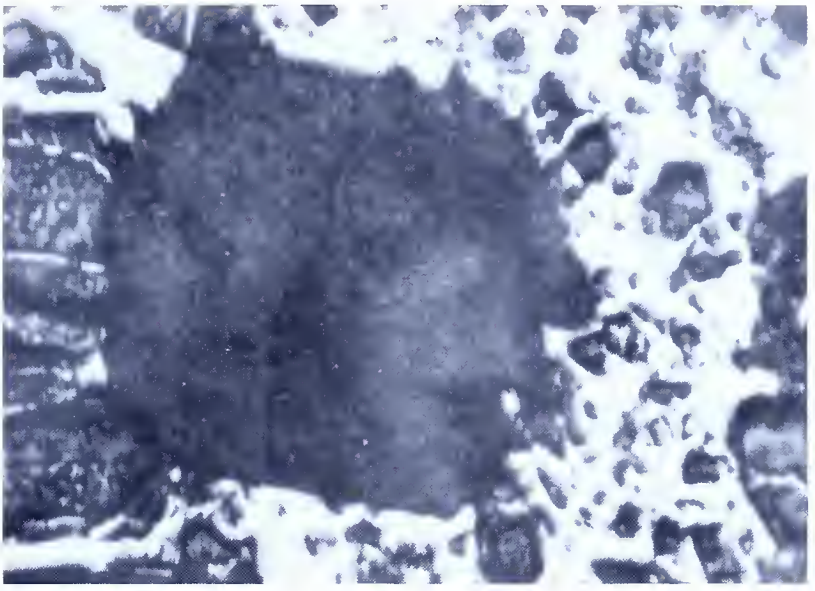


A. Bornite occupying cell interiors and rimmed by covellite (arrow). Galena (white) replaces the bornite cell interiors. Black areas are unreplaced carbon. Reflected light, X 180, Prospect 12.

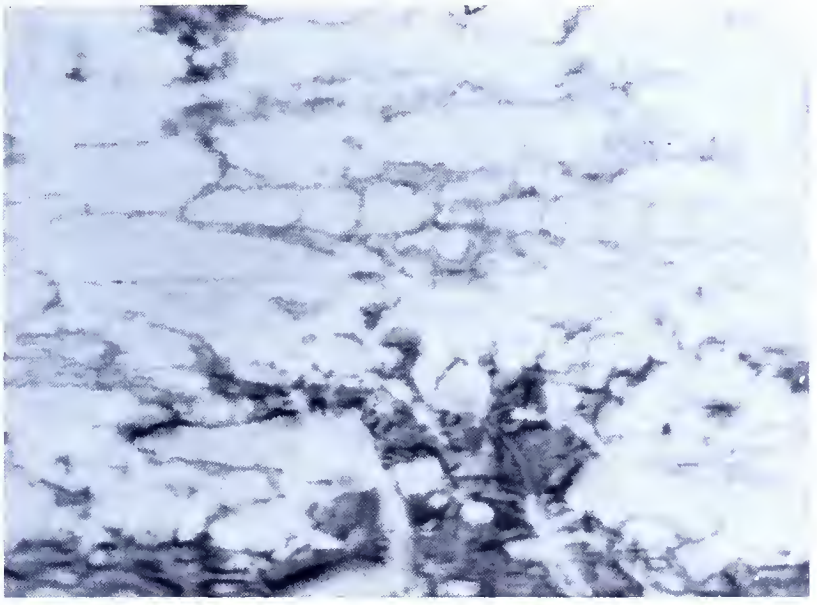


B. Sheaf-like barite (white) replaced by chalcocite. Transmitted light, X 21, Prospect 12.

Plate 6

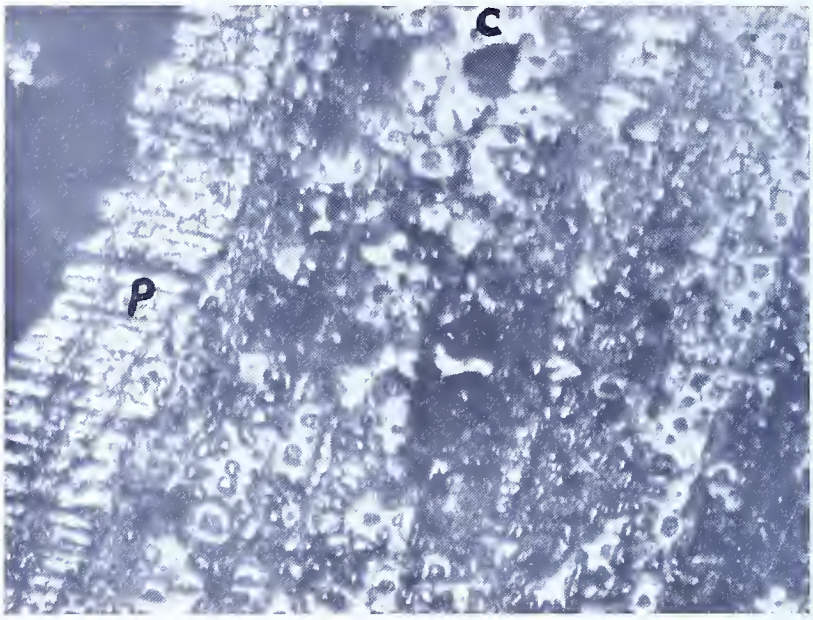


A. Subhedral quartz crystal (center) surrounded and embayed by galena (white) which also replaces vitrain along fractures. Filled resin blebs are visible in the vitrain. Reflected light, X 60, Prospect 12.



B. Relict cell textures preserved by chalcocite (gray) and covellite (darker gray) which occupies rims. Black is unreplaced carbonaceous material. Reflected light, X 180, Prospect 12.

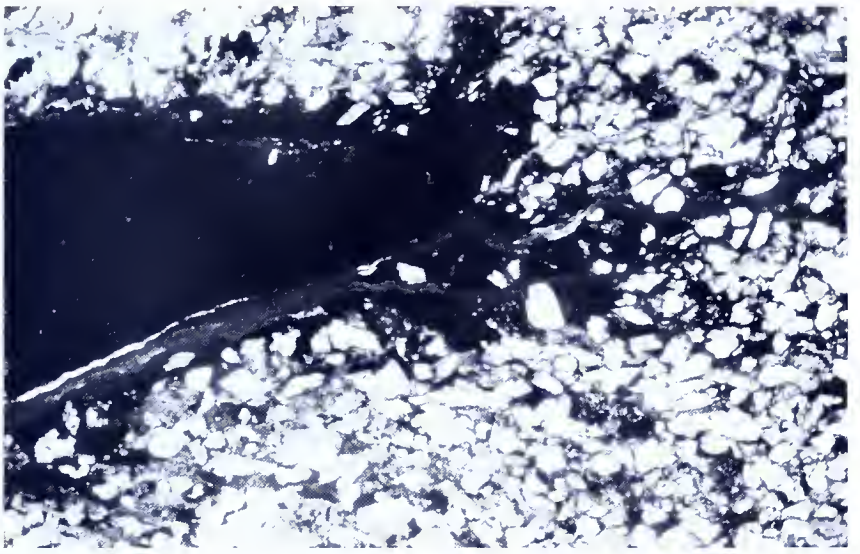
Plate 7



A. Pyrite (P) occurring as stringers and as blebs within vitrain; it is replaced by chalcocite (C). Black areas are carbonaceous material. Reflected light, X 60, Prospect 12.

B. Orthorhombic cleavage pattern in chalcocite. Reflected light, X 60, Prospect 12.

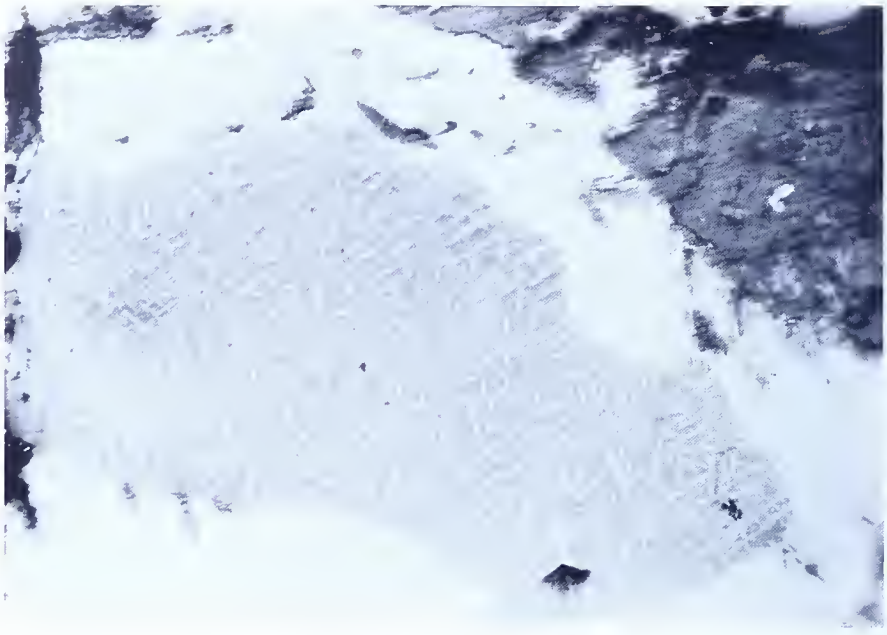
Plate 8



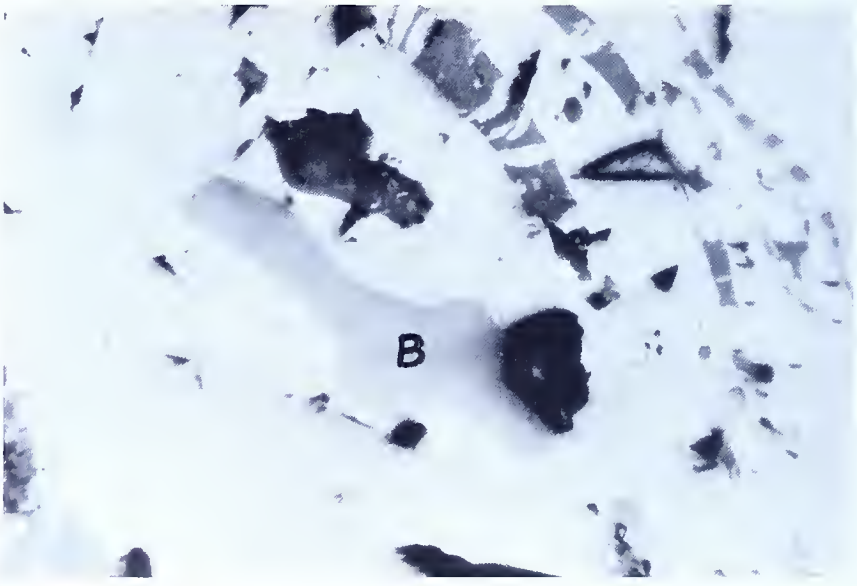
A. Chalcocite stringer (black) replacing surrounding siltstone. Transmitted light, X 21, Prospect 12.

B. Bornite (dark gray) containing very fine exsolution lamellae of chalcopyrite. Bornite and chalcopyrite replaced by galena (light gray). Covellite is the last mineral in the sequence and fills fractures in the other sulfides. Reflected light, X 180, Prospect 12.

Plate 9



A. Part of same specimen after heating at 200° C. for 144 hours, quenching and repolishing. Exsolution lamellae are considerably enlarged and readily visible at the same magnification. Reflected light, X 180, Prospect 12.



B. Bornite (B) after heating for 170 hours at 300° C. The exsolution laths have disappeared, remixing having been achieved. Reflected light, X 180, Prospect 12.

Mode of Occurrence of the Uranium

It has already been noted that the radioactivity is unevenly distributed. Analyses performed by the U.S. Geological Survey and the U.S. Bureau of Mines on the most radioactive samples from various localities range from nil to .83 percent. X-ray spectrographic analysis (Appendix B, p. 71) indicates that uranium is not consistently present in measurable amounts. The quantity varies from locality to locality and also from place to place within any one mineralized zone.

In many cases radioactivity can be attributed to minor concentrations of secondary uranium minerals disseminated throughout the rock. However, in many prospects, secondary mineralization is not evident. In these cases the major portion of the radioactivity emanates from cupriferous carbonaceous material with associated copper mineralization. Fresh, unweathered, megascopically homogeneous carbonaceous material was separated from these radioactive specimens and subjected to proximate analysis, the results of which have been reported previously. The ash was analyzed spectroscopically for uranium and thorium. It contained 1 percent U_3O_8, equivalent to about 0.15 percent U_3O_8 in the original sample. A second sample exhibiting no visible secondary mineralization was subjected to X-ray spectrographic analysis. It contained uranium, copper, manganese, arsenic, and barium. Thus, the major portion of the uranium and some of the other elements seem to be associated with the carbonaceous material. Examination by thin section, polished section, binocular microscope, and X-ray diffractometer failed to disclose any primary uranium minerals. Autoradiographs show diffuse fogging from the carbonaceous material and blackening due to local aggregates of secondary minerals.

A more intensive mineralogic study would be necessary to positively establish the mode of occurrence of the primary uranium. However, based on the incomplete evidence available it is believed to be present either as an amorphous oxide disseminated in submicroscopic particles throughout the carbonaceous material or an urano-organic compound (Kelley and Kerr, 1958).

X-ray Spectrographic Analysis

Seventeen ore samples from various individual prospects and from the surrounding country rocks were analyzed. Two samples of coaly material, and pyrite nodules present in the upper Catskill, near Central, also were included (Appendix B, p. 71). Copper and iron are the elements most consistently present, manganese somewhat less so. Manganese is present in the host rocks and considered an indigenous component of the sediment, as is much iron, titanium, and zirconium. The uranium distribution is uneven and the element is not present in measurable amounts in all the

samples analyzed. Lead, barium, and arsenic were detected in the majority of the samples. The presence of the same group of elements as noted in the Triassic and Mississippian occurrences, points to a general chemical similarity between all the Pennsylvania sedimentary deposits. The only significant difference appears to be in the relative percentages of each element. The Devonian occurrences are high in copper and, in some instances, lead. The Mississippian occurrences at Mount Pisgah are high in uranium and vanadium, whereas the Triassic occurrences are highest in uranium. The various uranium districts on the Colorado Plateau have a similar distribution of elements.

The Coloration Problem

Since uranium mineralization is generally restricted to gray or green zones surrounded by red beds, the origin of these green units merits consideration. Red bed formations, of which there are numerous representatives throughout the world, normally contain gray to green interbeds. The literature on this subject is too voluminous to review in this paper, so that only a general summary of the problem will be made.

Thin-section study of the subgraywackes of the Catskill Formation indicates that the color difference, i.e. red, as opposed to gray and green, results from the presence or absence of interstitial hematite. Those units which contain little or no hematite are gray to green in color. Chlorite acts as a green coloring agent in the absence of hematite, 10 to 20 percent chlorite resulting in a distinct green hue, while those containing lesser amounts tend to be gray in color.

A recent summary of the problem of red bed genesis is given by Krynine (1949). He points out (p. 60) "that the term 'red bed' is a catchall for many sedimentary types produced under different conditions, the only common feature being the red color." He divided red beds into four general types:

1) Primary red beds—coloring matter was derived from source area, preserved at the site of deposition.
2) Post-depositional red beds—coloring was the result of oxidation of non-red materials at the site of deposition.
3) Secondary red beds—coloring matter was derived by reworking of earlier red beds.
4) Chemical red beds—coloring was derived from material precipitated from solution along with the sediment.

The Catskill Formation of Pennsylvania consists mostly of a wedge of clastic material which extended westward toward an inland sea. To the east its upper extent bordered on the piedmont of the Devonian highlands. The surface of this area probably consisted in great part of red saprolites

resulting from deep weathering and oxidation. In the Piedmont of the present southern Appalaehians, sueh red weathering products are eommon. The elimate of this area is warm and humid—very similar to what might be inferred for late Devonian time. Erosion of the Piedmont during periods of teetonie stability would have provided mueh primary red eoloring matter in addition to sands, silts and elays. However, during times of uplift ineision of the streams would provide fresh unoxidized partieles deposited as gray sands and muds.

Krynine (1949, p. 62) points out in his general diseussion that the preservation of the red eolor implies a predominanee of oxidation over reduetion, a eondition whereby free oxygen may eome into eontaet with whatever organie matter is eontained in the sediments. The organie matter is destroyed ehiefly by oxidation without any effeet on the iron of the surrounding sediments. Numerous plant impressions in the red shales and siltstones of the Catskill Formation are evidenee of the former presenee of earbonaeeous material.

If deposition is beneath the water table, as in stream ehannels, little oxygen is present to effeet a destruetion of the abundant earbonaeeous material. Instead, relatively soluble ferrous iron eompounds are formed through the redueing aetion of the earbon or by gases generated from the earbon reaetions. Ferrous iron is readily transported away from the earbon-rieh areas by ground water, then reoxidized and deposited in the surrounding red sediments.

Channel deposits are not neeessarily gray to green in eolor. It is only in those portions or poekets within the ehannels where sufficient earbonaeeous material is preserved that reduetion and redistribution of iron takes plaee. From field observations, gradations from gray and green to red ean be seen within single ehannel struetures. Careful observation reveals the presenee of earbon in only the gray and greenish zones.

In addition to gray or green lenses deseribed above, numerous smaller seeondary eolor ehanges are seen in the Catskill roeks. Irregularly mottled green and red areas are eommon and alteration from red to green is often observed along fraetures and bedding planes. Sueh seeondary alteration eommonly extends into a red unit from the base of an overlying gray to green sand lens. Solutions moving downward along joints and bedding planes from earbon-rieh beds will reduee iron to the soluble ferrous form so that it is readily earried away.

Thermal solutions assoeiated with mineralization also eould effeet eolor ehanges, primarily by leaehing out the interstitial hematite of the red sediments. However, eolor differenees are observed in equal abundanee and magnitude in both mineralized and barren areas. Thus, any leaehing by mineralizing solutions must have been quite loeal. The gray or green eolor

of the sediments in almost all cases can be more properly attributed to sedimentary or diagenetic processes.

Bornite-Chalcopyrite Unmixing Textures

The bornite-chalcopyrite latticework seen in polished section is interpreted as an exsolution phenomenon. Such features are often indicative of elevated temperatures of formation and have been extensively used as geological thermometers (Ingerson, 1956).

Edwards (1947) presents an excellent summary of the sulfide exsolution problem. The following two paragraphs are derived in part from his observations.

Substitutional solid solution is the type considered to be most common in the ore minerals. If the respective diameters of solute and solvent atoms differ by less than 14 percent to 15 percent, extensive solid solution can occur. Solid solutions in metallic structures are essentially unstable systems made possible by the development of disorder in the atomic structures at high temperatures. The anion lattices generally remain intact but the metal lattices become more or less disordered. If two minerals with a common sulfur lattice come into contact, solid solution can take place, but with decreasing temperature reordering tends to occur.

The unmixing of a solid solution is thought to take place by diffusion. The solute atoms diffuse through the lattice of the solvent substance forming an exsolved phase usually oriented in certain preferred directions. The rate of unmixing is higher at elevated temperature because of the increased diffusion rate. In reheating incompletely unmixed sufides, exsolution should be promoted up to the temperature at which disorder in the metal lattices becomes sufficient to permit remixing to begin. At temperatures in the vicinity of this critical point remixing can be achieved only by maintaining the temperature over long periods of time. The temperature up to which unmixing occurs or above which solid solution begins, is dependent in many cases, on the concentration of the solute in the particular specimen. In general in metal alloy systems, it might be said that the lower the concentration of the solute, the lower the temperature at which unmixing can occur.

The bornite-chalcopyrite solid solution series has been studied previously but the results have not been sufficiently conclusive to merit use in this study. Schwartz (1931) gave a temperature of 475° C. for the remixing of specimens taken mostly from the prophyry copper deposits of the southwestern United States. Ingerson (1956, p. 361) reports that Sugaki and Yamae (1950) gave a temperature of 300° C. on samples from Japan. More recent work on the problem has been done by Sugaki (1951) and Tekeuchi and Nambu (1956). Kullerud, at the Geophysical Labor-

atory, Washington, is now engaged in a complete study of the Cu-Fe-S system and Greig, Pennsylvania State University, is working on the bornite-chalcopyrite series, in part, with samples provided by the author.

Since these previously published temperatures (475° C., 300° C.) are excessive for the inferred conditions of formation of the deposits in question, heating experiments were undertaken in an attempt to determine the minimum temperature of formation for these particular occurrences.

Bornite specimens from Prospect 12 containing minute lamellae of chalcopyrite were sealed in glass tubes and heated for various lengths of time (Table 6). They were then subjected to a cold water quench and re-polished for examination. The furnace used was a "Blue Electric" Model M15A, with a temperature range from 66° C. to 1090° C.

Table 6

1)	75° C.	for	2 hours
2)	190° C.	for	24 hours
3)	190° C.	for	350 hours
4)	200° C.	for	144 hours
5)	300° C.	for	170 hours
6)	400° C.	for	120 hours
7)	400° C.	for	160 hours

Samples 1, 2, 3, and 4 showed varying increased degrees of exsolution. The chalcopyrite laths faintly visible at high magnifications were easily discernible at lower power after the experiments. Some of the exsolved chalcopyrite segregated into discrete blebs rather than into oriented blades. The total volume of chalcopyrite before heating was approximately 3 percent (based on photomicrograph point counts). After heating, the amount increased to approximately 20 percent. Samples 5 and 6 showed partial remixing, i.e. portions of the sample no longer contained any exsolved chalcopyrite. In sample 7, no chalcopyrite was visible at the highest possible magnification and it is inferred that complete remixing was achieved.

The results of this study are inconclusive, although seeming to indicate remixing temperatures in accord with those previously reported. The investigation definitely suggests, however, that the problem of exsolution in the Cu-Fe-S system is more complicated than envisioned by previous workers.

The increased amount of exsolved material present after heating in runs 1-4, seems to indicate that a considerable amount of chalcopyrite was still dissolved in the original samples. Before heating, the original color was a distinct pinkish orange while after exsolution the color was a pinkish purple. It is possible that the color of bornite in polished section is a function of the amount of solute such as chalcopyrite, tetrahedrite

or chalcocite. However, this could not be confirmed and a possible alternative is that the additional chalcopyrite was generated at the expense of bornite with the development at high temperatures of a new copper-rich phase, akin to chalcocite or digenite in composition.

Initially it was hoped that the temperature of homogenization might indicate the minimum temperature of formation (McCauley, 1958). However, Gaucher (1959) pointed out that this temperature may correspond to a point at which homogenization takes place rapidly and may not correspond to any definite point on the subsolidus curve. He further suggests that if additional chalcopyrite can be exsolved from bornite upon heating, that it is possible that the specimen was never subjected to such a temperature in its original environment. If this is the case, the bornite—chalcopyrite pair may have formed below 75° C. which was the lowest temperature at which increased exsolution was observed in this study.

Sulfur Isotope Study

The determination of sulfur isotope ratios has become a useful tool to students of ore genesis, although the method does not supercede other established means of investigation. It does, however, provide new criteria by which genetic theories may be more critically examined (Jensen 1958, 1959).

Twelve samples from various Pennsylvania mineral occurrences were analysed by M. L. Jensen and C. W. Field of Yale University. These are listed in Table 7 and have been compared with standard ranges for sedimentary, biogenic, and igneous isotope ratios (Rankama, 1954, p. 277) in Fig. 11.

Samples one and two are not from uranium occurrences, but were included in order to check the ratios of two different types of mineralization which occur in the general area of the uranium. The results indicate that sample one probably formed under sedimentary conditions while sample two is probably of hydrothermal origin since it shows no S^{34} depletion.

Sample three, from one of the occurrences in Triassic beds, shows some depletion in S^{34}, but far less than the following samples, all from Devonian occurrences. This Triassic sample has the same ratio, within the limitations of the method, as does the one sample of magmatic hydrothermal origin (Marysvale, Utah) reported by Jensen (1958, p. 608).

Samples four through twelve all show significant depletion in S^{34}, which according to Jensen, strongly suggests that the sulfur contained in the occurrences is derived from organically produced hydrogen sulfide, not from magmatic solutions. The Colorado Plateau "sandstone type" uranium occurrences also exhibit this depletion in S^{34}.

Sulfur Isotope Ratios of Uranium-Sulfide Occurrences in Pennsylvania

Sample #	*Locality*	*Geologic Description*	S^{32}/S^{34}	$S^{34}/00$
1	Luzerne Co., Rt. 487 1½ mi. N. of Red Rock	Pyrite nodule from a black shale lens in the upper Catskill Formation	22.98 ± 0.02	– 34.7
2	Columbia Co., 2.5 mi. E. of Bloomsburg on Rt. 11	Galena and sphalerite from a replacement vein in the Lower Devonian limestones	21.65 ± 0.02	+ 25.2
3	Prospect 3, Locality List	Pyrite from ferruginous arkosic sandstone of the Stockton Formation	22.32 ± 0.02	– 4.7
4	Prospect 12, Locality List	Chalcocite and digenite associated with carbonaceous material, in the lower Catskill Formation	22.84 ± 0.02	– 28.4
5	Prospect 12, Locality List	Same as sample 4	22.83 ± 0.02	– 27.8
6	Prospect 12, Locality List	Same as sample 5	22.85 ± 0.02	– 28.6
7	Prospect 12, Locality List	Galena, bornite, chalcopyrite, chalcocite and covellite associated with carbonaceous material, in the lower Catskill Formation	22.64 ± 0.02	– 19.1
8	Prospect 9, Locality List	Bornite and chalcopyrite associated with carbonaceous material in the lower Catskill Formation	22.67 ± 0.02	– 20.7
9	Prospect 9, Locality List	Same as sample 8	22.72 ± 0.02	– 23.0
10	Prospect 9, Locality List	Same as sample 9	22.69 ± 0.02	– 21.7
11	Prospect 35, Locality List	Pyrite and chalcocite associated with carbonaceous material, in the lower Catskill Formation	22.72 ± 0.02	– 22.9
12	Prospect 35, Locality List	Same as sample 11	22.72 ± 0.02	– 23.0

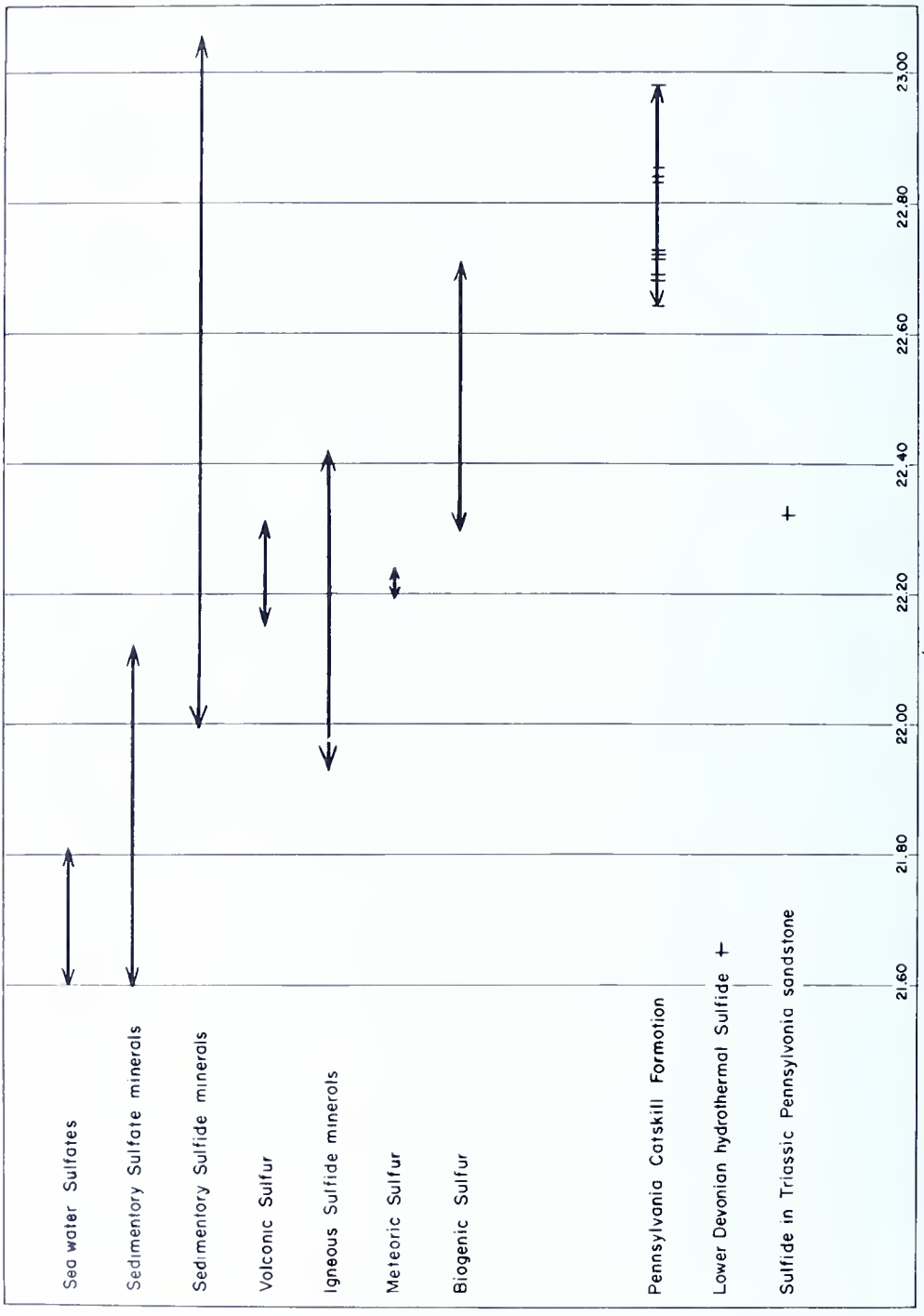


Figure 11. Sulfur isotope ratios for Pennsylvania compared with standard

However, according to Jensen (1958, p. 609), even more diagnostic of organically derived hydrogen sulfide is a relatively broad spread in ratios from the same deposit, even of immediately adjacent samples. With the exception of sample seven, which contains different mineral species than the other samples from Prospect 12, the spread in actual ratios between samples of the same locality is very small or actually non-existant.

The ratios within individual Colorado Plateau deposits do vary over a broad range. Jensen (1959, p. 389) attributed this to the fact that experimental evidence indicates that the fractionation efficiency of bacteria varies erratically with time.

If sulfides are produced contemporaneously as hydrogen sulfide is generated, it is likely that the S^{32}/S^{34} ratio of these sulfides will vary depending on the efficiency of the organisms at a particular place at a particular time. However, if the formation of metallic sulfides takes place considerably later than the generation of the hydrogen sulfide the ratios may be high but also may be more uniform. During the time interval between hydrogen sulfide generation and sulfide mineral deposition the gases generated through the host rock would have an opportunity to mix, resulting in these uniformly high sulfide ratios.

GENESIS OF THE URANIUM OCCURRENCES IN PENNSYLVANIA

Review of Previous Genetic Theories

Before the present interest in uranium a sizeable literature already existed on the genesis of the "sandstone" deposits. Studies prior to 1940 (Lindgren, Graton, and Gordon 1910, Rogers 1916, Basten 1933, Finch 1933 and Fischer 1937) attempted to explain the presence of the sulfides chiefly chalcocite, but also pyrite, bornite, chalcopyrite, galena and both blue (digenite) and white chalcocite. The abundance of chalcocite convinced the majority of these early workers that the deposits were derived from meteoric waters. Graton (1910) however, favored an origin from ascending thermal solutions and Lindgren (1933) admitted that thermal solutions of meteoric origin might have formed some of the deposits.

A voluminous literature has accumulated within the last ten years on the genesis of the Colorado Plateau deposits. The majority of these investigations have been concerned with an explanation of the origin of the uranium while the associated sulfide mineralization has received little attention. It is for this reason that the results have been, at least to the present, somewhat inconclusive. Fortunately, this trend has been reversed in the last few years, particularly with the initiation of isotopic studies of the sulfur and lead.

Some of the early investigators of the present period considered that the "sandstone type" mineralization was syngenetic. This viewpoint was contrary to the observations of the "pre-uranium" school and also to subsequent exhaustive field and laboratory investigations. The simple syngenetic approach is, therefore, no longer widely considered.

A second theory, which has attracted a large number of adherents, is the circulating ground water theory. Gruner (1959), proposed a multiple migration accretion hypothesis which assumes that the metal ions were ultimately derived from the erosion of adjacent crystalline highlands and carried by ground water solutions into basins of deposition where precipitation occurred in the reducing environments of swamps and stream channels. These original accumulations would be penecontemporaneous with sedimentation and of low grade. These would, in turn, be eroded and the metals redeposited in similar environments, but in higher concentrations. This process of erosion and redeposition at normal ground water temperatures would continue until sizeable economic concentrations of uranium and other metals resulted. However, significant alteration effects have been noted at certain localities (Temple Mountain), so that some investigators have suggested that mineralization was effected by thermal solutions of connate or meteoric water whose metal content was derived from the surrounding sediments (Jensen, 1959).

A third school maintains that these deposits were formed essentially by warm to moderately hot solutions, possibly contaminated with ground water, but whose metal content was derived primarily from the basement (Kerr, 1958). This theory is based on the presence of hydrothermal alteration effects at certain localities within the Plateau and the existance of more definitely established hydrothermal uranium deposits on its periphery.

Conclusions

The following conclusions are based for the most part on observations made for the occurrences in Devonian rocks in Pennsylvania since they are the most numerous and most fully investigated. The occurrences in Triassic and Missippian rocks are also of the "sandstone type" so that in general, what is said for the one can be applied to the others.

The first theory considered for the uranium occurrences in Pennsylvania is the descending meteoric hypothesis. Downward moving solutions may have leached small amounts of uranium and other metals from syngenetic accumulations in the overlying sediments and these metals may have been deposited in favorable environments at lower levels. The black shales associated with the Pennsylvanian Coal Measures do exhibit higher than normal radioactivity in some areas.

However, stratigraphic evidence argues against this theory. In the vicin-

ity of the Allegheny Front, where the occurrences are most numerous, the mineralization is apparently confined to the lower portion of the Catskill Formation. This part of the section contains numerous gray to green carbonaceous zones, many of which are mineralized. However, the upper Catskill Formation also contains a large thickness of carbonaceous gray to green sediments but is barren of reported mineralization. This may simply reflect insufficient prospecting along the steep, heavily wooded mountain slopes where the upper Catskill Formation crops out. Nevertheless, the two zones are separated by approximately 1,000 feet of predominantly red shale. This thick, relatively impermeable unit should have acted as a barrier to the downward movement of solutions. Thus, it seems likely that if uraniferous solutions did migrate downward from areas of syngenetic accumulation in the carboniferous sediments, the upper horizon would be extensively mineralized and the lower practically barren. Since the reverse is the case, the descending meteoric water theory does not appear to be applicable.

Another theory to be considered is that mineralization was essentially penecontemporaneous with sedimentation. However, in polished section, the sulfides fill fractures in the coalified plant material. These fractures are for the most part regularly oriented and the material breaks into small rectangular fragments. The fractures may be of the same origin as the joints or cleats observed in larger coal seams or they may be shrinkage cracks. In either case their presence indicates that mineralization could not have been strictly syngenetic since it must have post dated at least the early stages of coalification.

True syngenetic mineralization did occur on a minor scale in the black shales of the Triassic and possibly of the Devonian sections. The argillite of the Lockatong Formation of the Deleware Valley does exhibit higher than normal background radioactivity (McCauley, 1957, p. 19). Several small black shale lenses containing pyrite nodules were noted in the upper Catskill Formation on the Allegheny Plateau. However, they did not exhibit higher than background radioactivity in the field and X-ray spectrographic analysis failed to disclose any measurable amounts of uranium or copper. This different type of mineralization, where actually present, has a bearing on the sandstone occurrences only in so far as the latter might be derived from the former by descending solutions. This hypothesis has already been rejected on the basis of stratigraphic evidence.

The multiple-migration accretion hypothesis of Gruner supposes that mineralization occurred near the surface at normal ground water temperatures. The suite of sulfides present, i.e., bornite, chalcopyrite, galena and digenite, and the evidence of exsolution phenomena strongly suggest conditions of formation dissimilar to those at or near the ground surface. Al-

though the heating experiments conducted on the bornite-chalcopyrite series indicate a minimum possible temperature of formation near 75° C. (possibly somewhat lower) we have no positive evidence for the actual temperature of formation. The fact that only a small percentage of the chalcopyrite actually exsolved from the bornite in nature might indicate, contrary to Gaucher's viewpoint, that deposition occurred at temperatures somewhat higher than the possible minimum and that cooling in the solid state was rapid, resulting in incomplete exsolution. In addition, the increased amount of quartz recrystallization noted in and near the mineralization can be interpreted as a result of thermal solutions moving through the porous paleostream channels.

The two remaining hypotheses are the ground or connate water "hydrothermal" and the magmatic-hydrothermal theories. Evidence both for and against each can be offered, so that final judgment might best be reserved pending the outcome of more comprehensive studies, particularly in regard to the geochemistry of this type mineralization.

In general, the sulfur isotope data supports the ground water "hydrothermal" theory. The Colorado Plateau ores are similarly depleted in S^{34} and are classified by Jensen (1959) as ground water hydrothermal deposits. The data does suggest that the sulfur in these occurrences was derived from organically produced hydrogen sulfide and not from magmatic sources. Deposits of known magmatic hydrothermal origin seldom exhibit S^{34} depletion. However, the spread of the ratios from individual occurrences is not as great as in the Plateau deposits. Conceivably ground water or in the Pennsylvania case, more probably, connate waters moving beneath impermeable barriers (middle Catskill red shale) could leach minor amounts of uranium and other metals from the host rock. These metals would ultimately be precipitated in carbonaceous zones by organically produced hydrogen sulfide. Since sulfate reducing bacteria are not known to exist above 100° C. the temperature of deposition would be relatively low, possibly in the vicinity of 75° C.

An argument against the connate or ground water hydrothermal theory is that deposits of known hydrothermal character do exist in the general area of the Devonian, Mississippian and Triassic occurrences. Since, metals have been added to the upper crust in the vicinity of the uranium mineralization, the problem of finding a source for these occurrences is not as great as it seems to be on the Colorado Plateau. Solutions carrying metals from the basement could conceivably have moved upward through fractures which are known to exist at depth within the Allegheny Plateau (Fettke, 1954). These solutions may have become contaminated with ground or connate water at shallower depths and may have ultimately deposited their metals in areas of hydrogen sulfide concentration. Although the environ-

ment and means of deposition are not the same as in vein or replacement type hydrothermal deposits, the ultimate source of the metals may be identical i.e. deep seated magmatic activity.

If the metals were originally derived from a magmatic source, considerable lateral migration must have taken place before final deposition. The porous network of paleostream channels in the lower Catskill beds, and the thick overlying middle Catskill shale suggest ideal conditions for lateral migration.

URANIUM OCCURRENCES IN PRECAMBRIAN ROCKS

Introduction

Although the primary concern of this study has been the sandstone type deposits, attention has been given to occurrences in the igneous and metamorphic rocks. Prospects of a similar nature are also reported in the crystalline highlands of New Jersey and New York. They are all characterized by the presence of uraninite and thorite in pegmatitic lenses of an injection gneiss. In many places they are associated with magnetite ores, generally considered to be hydrothermal in origin.

General Description

Prospect 43, near the town of Pikesville, Berks County is an abandoned iron prospect pit. The radioactive areas are confined to pegmatitic pods and stringers which are generally conformable with the foliation of the surrounding gneiss, north 40° east, 75° south, but are also locally cross cutting. Several bands of titaniferous magnetite, also conformable with the host rock, are located at the northwest end of the pit. These apparently originated by replacement rather than injection, since the contacts are not sharp and disseminated ore is present in decreasing amounts away from the contacts.

Significant radioactivity is present at the places indicated in Figure 12. The owner of the property reports U_3O_8 values up to 0.213 percent. X-ray spectrographic analyses performed by the writer disclosed the presence of uranium, thorium, iron, and manganese.

The general area is outside the southernmost extent of Pleistocene glaciation so that deep, residual weathering is common. The light-colored microcline gneiss at the southeast end of the face is friable, and hand specimens readily disintegrate. The upper portion of the mineralized zone is now saprolite, in the process of creeping down the slight overhead slope.

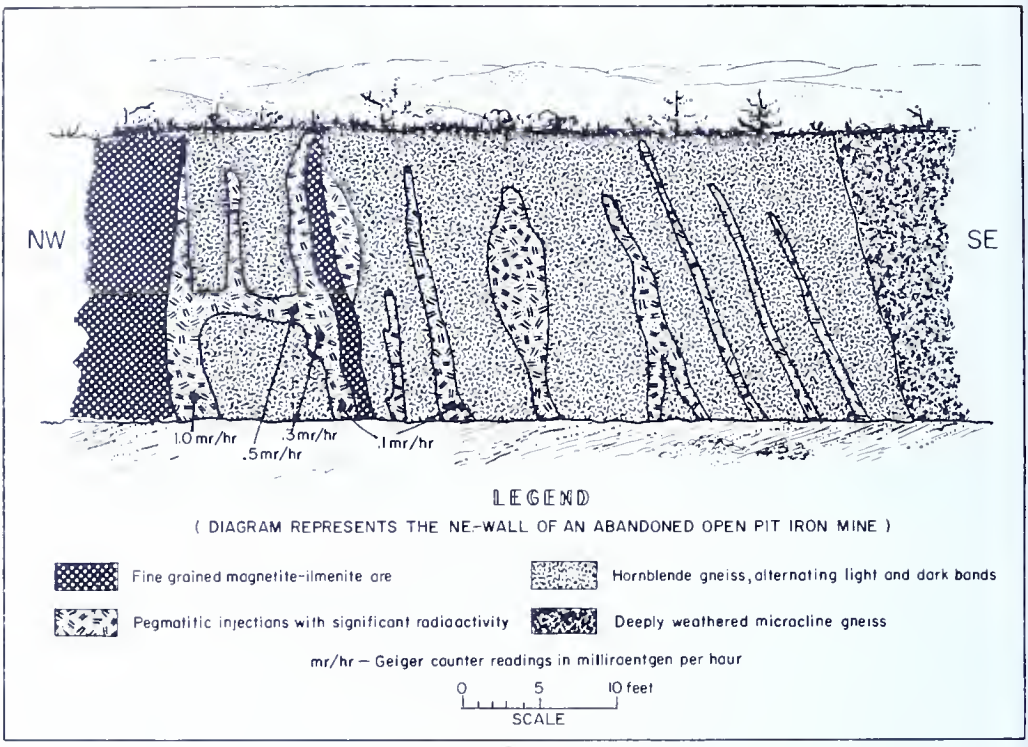


Figure 12. Prospect 43.

Petrology and Mineralogy

Four distinct rock types are exposed in the pit face. The friable microcline gneiss containing quartz and minor biotite was too badly decomposed to permit thin-section examination. The hornblende gneiss consists essentially of brownish-green hornblende, locally altered to chlorite. The feldspar present is not zoned and is considerably kaolinized. Minor amounts of late magnetite replace both the hornblende and the plagioclase. The iron-bearing rocks consist of a fine-grained intergrowth of magnetite and ilmenite, presumably an exsolution relationship. Also present are hornblende and plagioclase, both of which are embayed and replaced by iron minerals. The pegmatitic material consists of relatively coarse-grained quartz and microcline. Individual feldspar crystals are about 10 mm in length and the quartz is considerably finer grained, showing strain shadows and undulatory extinction. Twin lamellae of the badly altered feldspars are bent and distorted, as are the biotite grains. Numerous voids filled with yellow secondary uranium minerals are present throughout.

No primary uranium oxides could be isolated by heavy mineral separations, but yellow secondary minerals were obtained. It is inferred that

deep weathering has oxidized the primary minerals, at least in the surface zones where the samples were taken. Numerous voids, showing the outlines of former crystals, are filled with secondary minerals, suggesting the presence of primary oxides before weathering.

Genesis

The genesis of this type occurrence is generally agreed upon by most geologists—in contrast to the so-called "sedimentary" types. Uranium is known to be concentrated in the late stage differentiates of silicic igneous magmas (McKelvey, Everhart, Garrels, 1956, p. 465). It is believed that the uranium was concentrated in a late, acid-rich phase of the magma which was forcibly intruded into the overlying rocks, resulting in the injection gneiss now exposed. The "differentiate" or magmatic type as contrasted to the hydrothermal or "sedimentary" type normally contains considerable amounts of thorium, as was confirmed by X-ray spectrographic analysis.

ECONOMIC POTENTIAL OF THE SEDIMENTARY TYPE OCCURRENCES

The principal domestic source of uranium at present time is the Colorado Plateau area. A similarity between the deposits of the Plateau and those of Pennsylvania has been pointed out in this report. The mineralogy, association with carbonaceous material, and type of host rock are some of the common features. The greatest difference from the standpoint of economics is the size of the deposits and grade of the ore. It might be said that the Pennsylvania occurrences reproduce the features of the Plateau deposits "in miniature." All the occurrences now known are too small to be profitably worked, although several of the larger prospects would merit further exploration, if economic conditions were favorable.

A major disadvantage at the present time is the lack of a concentrating mill in the vicinity. The nearest mill adapted to handling ore of this type is on the Colorado Plateau. Material averaging at most 0.3 percent U_3O_8 cannot be shipped economically a distance of 1,500 miles before concentration. In order to construct a mill of even modest capacity it would be necessary to establish the presence of sufficient quantities of ore to guarantee a constant supply over a period of years, which cannot be done at this time.

In lieu of trying to develop a single ore body to justify a mill, the numerous small occurrences along the Allegheny Front might be worked on a cooperative basis. One after another of the small bodies could be mined

primarily by surface stripping, and the ore funneled into a central stockpile. Present indications are that hundreds of small pods exist in the area so that sufficient tonnage might be developed. However, since leases on the various properties are now held by many different individuals, considerable difficulty would be encountered in consolidation.

BIBLIOGRAPHY

Barrell, Joseph (1907), *Origin and significance of the Mauch Chunk Shale,* Geol. Soc. Am. Bull., vol. 18, pp. 449-476.

———— (1913), *The Upper Devonian delta of the Appalachian Geosyncline,* Am. Jour. Sci., 4th ser., vol. 36, pp. 429-472.

Barton, P. B., and Behre, C. H., Jr. (1954), *Interpretation and Evaluation of the Uranium occurrences near Goodsprings, Nevada,* U.S. Atomic Energy Comm. Rept. RME 3119.

Bastin, E. S. (1933), *The chalcocite and native copper types of ore deposits,* Econ. Geol. vol. 28, pp. 407-446.

Bateman, A. M. (1950), *Economic Mineral Deposits,* Wiley, New York, p. 38.

Brown, J. S. (1943), *Supergene magnetite,* Econ. Geol., vol. 38, pp. 137-148.

Buerger, N. W. (1941), *The chalcocite problem,* Econ. Geol., vol. 36, pp. 19-44.

Butler, R. D. (1938). *A "Red-Beds" type copper occurrence, Wyoming Co., Pennsylvania,* Econ. Geol., vol. 33, pp. 625-634.

Dyson, J. L. (1954), *Relation of stratigraphy and structure to uranium occurrence near Mauch Chunk, Pennsylvania,* Proc. Pa. Acad. Sci., vol. 28, pp. 124-134.

Earl, K. M. (1950a), *Investigation of the Almedia lead-zinc deposit, Columbia County, Pennsylvania,* U.S. Bur. of Mines, Rept. Inv. 4743.

———— (1950b), *Investigation of the New Galena lead deposit, Bucks County, Pennsylvania,* U.S. Bur. of Mines, Rept. Inv. 4703.

———— (1950c). *Investigation of the Perkiomen Creek copper deposits, Montgomery County, Pennsylvania,* U.S. Bur. of Mines, Rept. Inv. 4666.

Edwards, A. B. (1947), *Textures of the ore minerals,* Australasian Inst. of Mining and Metall., Melbourne.

Fettke, C. R. (1954), *Structure-contour maps of the plateau region of north-central and western Pennsylvania,* Pa. Geol. Survey, 4th ser., Bull. G 27.

Finch, J. W. (1933), *Sedimentary copper deposits of the western states, in ore deposits of the Western States,* New York, p. 482.

Fischer, R. P. (1937), *Sedimentary deposits of copper, vanadium-uranium and silver in the southwestern United States,* Econ. Geol., vol. 32, pp. 906-951.

Frondel, Clifford, Riska, Daphne, and Frondel, J. W. (1956), *X-ray powder data for uranium and thorium minerals,* U.S. Geol. Survey Bull. 1036-G.

Gaucher, Edwin H. (1959), *Copper uranium deposits in Pennsylvania,* Econ. Geol., vol. 54, pp. 1126-1127.

Groves, A. W. (1951), *Silicate analysis,* George Allen and Unwin Ltd., London, pp. 88-90.

Gruner, J. W. (1952), *New data on synthesis of uranium minerals,* U.S. Atomic Energy Comm. Ann. Rept., RMO-983, pt. 1.

———— (1956), *Concentration of uranium in sediments by multiple migration-accretion,* Econ. Geol., vol. 51, pp. 495-520.

Ingerson, Earl (1955), *Methods and problems of geologic thermometry,* Econ. Geol., 50th Anniv., vol., pp. 359-362.

Jensen, M. L. (1958), *Sulfur isotopes and the origin of sandstone-type uranium deposits,* Econ. Geol., vol. 53, pp. 598-616.

———— (1959), *Sulfur isotopes and hydrothermal mineral deposits,* Econ. Geol., vol. 54, pp. 374-394.

Johnson, M. E., and McLaughlin, D. B. (1957). *Guidebook for Field Trips, Atlantic City Meeting,* Geol. Soc. Am., pp. 31-68.

Kelly, D. R., and Kerr, P. F. (1957). *Clay alteration and ore, Temple Mountain, Utah,* Geol. Soc. Am. Bull., vol. 68, pp. 1101-1116.

———— (1958), *Urano-organic ore at Temple Mountain, Utah,* Geol. Soc. Amer. Bull., vol. 51, pp. 1359-1390.

Kerr, P. F. (1958), *Uranium emplacement in the Colorado Plateau,* Geol. Soc. Am. Bull., vol. 69, pp. 1075-1111.

Klemec, Harry, and Baker, R. C. (1954), *Occurrences of uranium in Carbon County, Pennsylvania,* U.S. Geol. Survey Circ. 350.

Krauskopf, K. B. (1955), *Sedimentary deposits of rare metals,* Econ. Geol., 50th Anniv. vol., pp. 411-427.

Krumbein, W. C., and Sloss, L. L. (1951), *Stratigraphy and sedimentation,* Freeman, San Francisco, pp. 132-134.

Krynine, P. D. (1949), *The origin of red beds,* N.Y. Acad. Sci. Trans., Ser. 2, vol. 2, no. 3.

Lesley, J. P. (1892), *A summary description of the geology of Pennsylvania,* Final report, Pa. 2nd Geol. Survey, vol. 3, pp. 1567-1628.

Lindgren, Waldemar (1933), *Mineral deposits,* McGraw-Hill, New York, p. 409.

Lindgren, Waldemar, Graton, L. C., and Gordon, C. H. (1910), *The ore deposits of New Mexico,* U.S. Geol. Survey Prof. Paper 68, pp. 76-78.

Lord, N. W. (1913), *Analysis of coals in the United States,* U.S. Bur. of Mines Bull. No. 22, pt. 1.

McCauley, J. F. (1957), *Preliminary report on the sedimentary uranium occurrences in the state of Pennsylvania,* Pa. Geol. Survey, PR 152.

———— (1958), *Supergene copper uranium deposits, Nova Scotia,* Econ. Geol. Vol. 53, pp. 1038-1042.

McKelvey, V. E., Everhart, D. L., and Garrels, R. M. (1956), *Origin of uranium deposits,* Econ. Geol. 50th Anniv. vol., pp. 492-510.

Miller, L. J., and Kerr, P. F. (1954), *Progress report on the chemical environment of pitchblende,* U.S. Atomic Energy Comm., RME-3096, pt. 2, pp. 72-99.

Montgomery, Arthur (1954), *Uranium minerals of the Mauch Chunk area,* Pennsylvania, Proc. Pa. Acad. Sci., vol. 28, pp. 102-110.

Moore, E. S. (1940), *Coal,* John Wiley & Sons, New York, pp. 175-176.

Papenfus, E. B. (1931), *Red bed copper deposits in Nova Scotia and News Brunswick,* Econ. Geol., vol. 26, pp. 314-330.

Rankama, Kalervo (1954), *Isotope Geology,* McGraw-Hill Book Co., p. 277.

———— **and Sahama, T. G.** (1950), *Geochemistry,* Univ. of Chicago Press, Chicago, p. 742.

Reed, D. F. (1949), *Investigation of the Pickering Creek lead-zinc deposits, Chester County, Pennsylvania,* U.S. Bur. of Mines, Rept. Inv. 4451.

Rogers, A. F. (1916), *Origin of copper ores of the "red beds" type*: Econ. Geol., vol. 11, pp. 366-380.

Schwartz, G. M. (1931a), *Textures due to unmixing of solid solutions,* Econ. Geol. vol. 26, pp. 739-763.

———— (1931b), *Intergrowths of bornite and chalcopyrite,* Econ. Geol., vol. 26, pp. 186-201.

Spiroff, Kiril (1938), *Magnetic crystals from meteoric solutions,* Econ. Geol., vol. 33, pp. 818-828.

Sugaki, A. (1951), *Thermal studies on the lattice intergrowth of chalcopyrite in bornite from the Akayama Mine, Japan,* Sci. Rept. Research Inst. A., Tohoku Univ., Sendai, pp. 19-28. (1952), Zentralblatt Fur Mineralogie, (Abstract), p. 265.

———— (1953), *Thermal study on the unmixing textures of sulphosalt minerals—on exsolution of the secondary solid solution (English summary),* Jour. Geol. Soc. Japan, vol. 59, pp. 1-14.

Tekeuchi, T., and Nambu, M. (1956), *On the genesis of the chalcopyrite lattice in bornite,* Sci. Rept., Research Inst. A. Tohoku Univ., Japan, vol. 8, pp. 31-44. Abstract: Mineralogical Magazine, Dec. 1957.

Tomlinson, C. W. (1916), *The origin of red beds,* Jour. Geol., vol. 24, pp. 153-179.

Weaver, C. E. (1958), *Geologic interpretation of argillaceous sediments,* Am. Assoc. Petrol. Geol. Bull., vol. 42, pp. 254-271.

Weed, W. H. (1911), *Copper deposits of the Appalachian states,* U.S. Geol. Survey Bull. 455, pp. 57-62.

Wherry, E. T. (1914), *Carnotite near Mauch Chunk, Pennsylvania,* U.S. Geol. Survey Bull. 580, pp. 147-151.

White, I. C. (1881), *The geology of Susquehanna County and Wayne County,* Pa. 2nd Geol. Survey, Report of Progress, vol. G-5.

———— (1883), *The geology of the Susquehanna River region,* Pa. 2nd Geol. Survey, Report of Progress G-7.

———— (1885), *The geology of Huntingdon County,* Pa. 2nd Geol. Survey, Report of Progress T-3.

Willard, Bradford, (1939), *The devonian of Pennsylvania,* Pa. Geol. Survey, 4th ser., Bull. G 19, pp. 253-381.

Yoder, H. S., Jr., and Eugster, H. P. (1955), *Synthetic and natural muscovite,* Geochim. Cosmochim. Acta., vol. 8, pp. 225-280.

GENERAL REFERENCES

Anonymous (1955), *Contributions to the geology of uranium and thorium,* U.S. Geological Survey, Prof. Paper 300.

———— (1955), *Geology of Uranium and thorium,* International Conference on the Peaceful Uses of Atomic Energy, Proceedings, vol. 6.

———— (1955), *Special Uranium Issue,* Econ. Geol., vol. 50, no. 2.

APPENDIX A

Prospect 1 *Location:* Hendricks Island, Bucks County, Doylestown Quadrangle (15′), Latitude—40° 24.32′ N, Longitude—75° 00.30′ W., see p. 6 of text.

Prospect 2 *Location:* Prallsville, Hunterdon County, N. J., Lambertville Quadrangle (15′), Latitude—40° 24.65′ N, Longitude —74° 59.22′ W., see p. 6 of text.

Prospect 3 *Location:* Raven Rock, Hunterdon County, N. J., Lambertville Quadrangle (15′), Latitude—40° 24.70′ N, Longitude—75° 01.90′ W., see p. 6 of text.

Prospect 4 *Location:* Round Knob, Huntingdon County, Broad Top Quadrangle (15′), Latitude—40° 13.22′ N, Longitude—78° 05.77′ W., see p. 12 of text.

Prospect 5 *Location:* Mt. Pisgah, Carbon County, Mauch Chunk Quadrangle (15′), Latitude—40° 52.25′ N, Longitude—75° 44.68′ W., see p. 10 of text.

Prospect 6 *Location:* Mauch Chunk Ridge, Carbon County, Mauch Chunk Quadrangle (15′), Latitude—40° 51.50′ N, Longitude 74° 43.90′ W., see p. 10 of text (references).

Prospect 7 *Location:* Penn Haven Junction, Carbon County, Mauch Chunk Quadrangle (15′), Latitude—40° 56.40′ N, Longitude—75° 44.70′ W., see p. 10 of text (references).

Prospect 8 *Location:* Butcher Hallow, Carbon County, Mauch Chunk Quadrangle (15′), Latitude—40° 55.50′ N, Longitude—75° 44.80′ W., see p. 10 of text (references).

Prospect 9 *Location:* Central, Columbia County, Laporte Quadrangle (15′), Latitude—41° 16.03′ N, Longitude 76° 22.20′ W. A prospect pit approximately 40 by 80 feet in size is located at the end of the east fork of an unused dirt road, 1,000′ from the paved highway between Sugarloaf School and Tri Mills.

Geology: A discontinuously exposed lens of greenish gray shale, about 5′ thick is present. The lens pinches out laterally within a distance of 20′. A small adit has been driven 4 to 5 feet into the lens on the northwest wall of the pit. Mineralization is confined to numerous ½ inch to 1 inch thick, discontinuous seams of carbonaceous material. These are partially replaced by sulfides and exhibit radioactivity varying from slightly above background up to readings of 1.5 mr per hour.

The sulfides present are pyrite, bornite, chalcopyrite, chal-

cocite, covellite, and a very minor amount of galena. Malachite is abundant as thin encrustations along bedding planes within the shale.

Prospect 10 *Location:* Central, Columbia County, Laporte Quadrangle (15′), Latitude 41° 16.12′ N, Longitude—76° 22.30′ W. Two prospect pits 10 by 15 feet are located at the end of the west fork of an unused dirt road approximately 2,000′ from the paved road between Sugarloaf School and Tri Mills.

Geology: Mineralization is confined to a weathered grayish layer of siltstone approximately one foot thick and traceable along the base of the ledge for a distance of 300 feet. The 6 foot ledge is capped by a micaceous red siltstone. Carbonaceous material is present in thin seams but is soft and unctuous as a result of weathering. Radioactivity is irregular but appears to be highest in areas of greatest carbon concentration. No sulfides were identified because of the weathered condition of the mineralized zone. Malachite is abundantly distributed as encrustations along the bedding planes of the shale and the surrounding siltstone.

Prospect 11 *Location:* Central, Columbia County, Laporte Quadrangle (15′), Latitude—41° 16.27′ N, Longitude 76° 22.50′ W. A small abandoned copper mine is located .3 mi. from Sugarloaf School on the south side of the road between Sugarloaf School and Tri Mills.

Geology: A four foot thick lens of gray shale overlain by several feet of reddish siltstone is exposed in a partially flooded pit approximately 20 by 20 feet in size. An adit has been driven below the sandstone layer for a distance of about 20 feet. Mineralization appears to be confined to thin carbonaceous seams at the contact between the shale and the siltstone. The carbon is in a weathered condition and no sulfides were recognized. Radioactivity is irregular with the highest counts only two to three times above background. Malachite is abundant along the bedding planes of the shale.

Prospect 12 *Location:* Central, Columbia County, Laporte Quadrangle (15′), Latitude—41° 16.36′ N, Longitude—76° 22.45′ W. An exploratory trench 20 feet in length at end of foot path, 500 feet north of road between Sugarloaf School and Tri Mills, .35 miles from Sugarloaf School.

Geology: Mineralization is confined to thin carbonaceous

seams within a one foot thick shale lens, interbedded with red and gray siltstones. The carbonaceous seams are partially replaced by sulfides. Pyrite, bornite, chalcopyrite, galena, digenite, chalcocite and covellite have been identified. The shale lens is abundantly impregnated with malachite along the bedding surfaces. Radioactivity ranges from 2 to 7 mr per hour throughout the mineralized portions of the lens, one of the highest readings obtained in any of the Devonian occurrences. The secondary uranium minerals metazeunerite and uranospinite were identified from dump samples exposed to the atmosphere for approximately eight months.

Shallow drill holes 20—30 feet down dip indicate that the lens has no persistence in the third dimension.

Prospect 13 *Location:* Central, Columbia County, Laporte Quadrangle (15′), Latitude—41° 16.38′ N, Longitude—76° 22.43′ W. Same as Prospect 12 but 33 feet higher in elevation and 180′ to the NE.

Geology: Traces of malachite and a background count about twice the regional average are present in a 5 to 10′ wide portion of a thin lens of gray clay gall calcarenite overlain by gray siltstone. The lens can be traced to the east of the prospect for about 150′ and to the west for 300′. The color of this calcarenite unit changes from gray near the mineralization to reddish gray a few tens of feet away. Mineralization is associated with small plant fragments, considerably weathered at the outcrop.

Prospect 14 *Location:* Central, Columbia County, Laporte Quadrangle (15′), Latitude 41° 17.08′ N, Longitude—76° 21.66′ W. A small excavation on north side of road, .7 mi. south of covered bridge over Fishing Creek. Road begins at the 1,007′ Bench Mark, .5 mi. south of Central.

Geology: Mineralization is confined to a lens of micaceous siltstone of indeterminate dimensions. Weathered plant fragments are present along the bedding surfaces. Radioactivity is only slightly above background although thin encrustations of malachite are relatively abundant along the bedding planes.

Prospect 15 *Location:* Central, Columbia County, Laporte Quadrangle (15′), Latitude 41° 17.12′ N, Longitude 76° 22.43′ W.

A long abandoned copper prospect pit about 5 feet deep and 10 by 15 feet in surface dimension is located on west

side of highway, .9 mi. south of Jamison City road junction in the town of Central.

Mineralization is confined to the bedding surfaces of a gray shale unit, two feet from the floor of the pit. Radioactivity is only slightly above background. A thin calcarenite unit was observed, interbedded with typical red to gray siltstones and shale.

Prospect 16 *Location:* Central, Columbia County, Laporte Quadrangle (15′). Latitude 41° 16.7′ N, Longitude 76° 23.05′ W.

A small recently excavated pit is located on the west side of the road to Central, .1 mi. N of intersection with Route 115.

Geology: Mineralization is confined to isolated plant fragments within a gray to tan siltstone unit. No shale is present but blocks of gray calcarenite were found on the floor of the pit.

Malachite was the only mineral observed. Radioactivity is slightly above background.

Prospect 17 *Location:* Beaver Lake, Lycoming County, Eagles Mere Quandrangle (15′). Latitude 41° 16.57′ N, Longitude 76° 34.62′ W.

A recently excavated pit, 30 by 60 feet and about 6′ deep is located directly behind an abandoned farm house 2.7 miles from the Beaver Creek Road, Rt. 115 intersection, 1 mi. NE of Lairdsville.

Geology: Within the pit a gray sandstone zone about 3 feet thick exhibits radioactivity on the order of .2 mr per hour. The radioactivity is generally associated with plant fragments within this zone. Secondary copper mineralization is extensive and malachite the most abundant mineral. Shallow drilling and test probing at various distances away from the pit indicate that the zone does not extend more than 6 to 10 feet in the third dimension. Lease holders of the property reported the following U. S. Bureau of Mines analysis on selected samples.

1) Jan. 3, 1957 .26% U (Chemical analysis)
2) March 27, 1957 .70% U (Radiometric Equivalent)
3) April 24, 1957 .83% U (Radiometric Equivalent)

Prospect 18 *Location:* Beaver Lake, Lycoming County, Eagles Mere Quadrangle (15′). Latitude 41° 17.26′ N, Longitude 76° 35.95′ W.

A large timbered adit is located near the base of a steep

cliff, .2 miles NE of the Beaver Lake, Lairdsville road junction. The adit is 8 by 8 feet and extends into the eliff for a distanee of 20 feet.

Geology: A small lens of grayish green shale, interbedded with reddish shale and siltstone, eonstitutes the mineralized zone. The lens is located about 8 feet from the portal of the adit. Radioaetivity ranges up to a maximum of 2 mr per hour at the base of the shale where a thin weathered seam of earbonaeeous material is present. Malaehite is abundant along bedding surfaees in the shale. Chaleocite, assoeiated with earbonaeeous material, was identified from dump samples.

Prospeet 19 *Location:* Beaver Lake, Lyeoming County, Eagles Mere Quadrangle (15′). Latitude 41° 17.34′ N, Longitude 76° 35.62′ W.

Two long abandoned eopper prospeets are loeated .5 miles north of road intersection mentioned at Prospect 18. The adits are at the base of a 25 foot ledge, 250 feet west of the road.

Geology: The adits, 75 yards apart, are unsafe to enter so that the exaet geologieal relationships are not known. Study of dump samples indieate that lenses of ealearenite are present as well as malaehite eoatings along bedding surfaces. No appreeiable amount of radioaetivity was noted.

Prospeet 20 *Location:* Beaver Lake, Lycoming County, Eagles Mere Quadrangle (15′). Latitude 41° 17.40′ N, Longitude 76° 36.16′ W.

A long abandoned adit is loeated .4 miles NNW of Prospeet 18 on the west bank of a small tributary on the west fork of Beaver Run. The adit is 10 feet wide, 6 feet high and about 8 feet deep.

Geology: The mineralization oeeurs at the base of a gray sandstone unit overlying a gray to reddish shale. A thin seam of earbonaeeous material is present at this eontaet. The material is replaeed by ehalcocite and seeondary malachite is abundant along bedding surfaees in the shale. Radioaetivity is greatest in areas of high sulfide eontent. Maximum readings, obtained at the outerop, were 1.5 mr per hour. Two other small prospeet adits are present 100 and 200 yards to the southwest, respeetively. These were not studied in detail beeause of their generally unsafe appearance.

Prospect 21 *Location:* Beaver Lake, Lycoming County, Eagles Mere Quadrangle (15′). Latitude 41° 17.55′ N, Longitude 76° 36.35′ W.

The prospect is near the crest of a north-south trending spur, .6 miles NW of Prospect 18.

Geology: Mineralization is associated with several thin carbonaceous seams within a tabular body of gray cross bedded siltstone. Chalcocite is present along with secondary malachite. Radioactivity is relatively high for a distance of about 50 feet in a north-south direction. Maximum readings at the outcrop were .2-mr./hr. The lease holder reported analyses of selected samples of .38 and .40 percent U, (U. S. Geological Survey).

Prospect 22 *Location:* Beaver Lake, Lycoming County, Eagles Mere Quadrangle (15′). Latitude 41° 17.55′ N, Longitude 76° 36.35′ W.

The prospect is located near the crest of NNE trending spur at the end of an unimproved road which trends SE from the 1,038 foot spot elevation, one mile east of Tivoli.

Geology: Mineralization is discontinuously present within thin carbonaceous seams for a distance of about 200 feet. The seams occur within gray siltstones surrounded by coarse-grained, cross bedded red sediments. Chalcocite and pyrite are present mainly in the mineralized stringers but minor amounts of disseminated sulfide occur in the gray siltstone adjacent to the stringers. Malachite and azurite along with metazeunerite and uranspinite are the secondary alteration products (Fig. 13).

The radioactivity is unevenly distributed and high counts are obtained in areas devoid of secondary uranium mineralization. The highest readings obtained at the outcrop were 7 mr/hr. equalled only at two other prospects in Pennsylvania (Prospects 5, 12). The lease holder reported an analysis of high grade ore at .83% U (U. S. Geological Survey).

Two small test adits have been driven into the ledge face. That at the north end dates from the latter part of the 19th century the other, was opened during the summer 1957. Neither adit extends more than 20 feet and the mineralized seams pinch out within 10 to 15 feet of the portals.

Prospect 23 *Location:* Beaver Lake, Lycoming County, Eagles Mere Quadrangle (15′). Latitude 41° 18.30′ N, Longitude 76° 41.00′ W.

A small recently excavated prospect pit is located at an elevation of approximately 900 feet, on the ridge, due NW of 698 foot bench mark, one mile north of Tivoli.

Geology: Two thin weathered carbonaceous seams are present at the back of the pit. They are within a gray siltstone unit, overlain by flaggy reddish sandstone. The two zones are separated by about one foot of gray siltstone. The average reading in the pit is about .4 mr/hr. and the highest obtained was 1 mr/hr. Malachite is locally abundant.

Prospect 24 *Location:* Beaver Lake, Lycoming County, Eagles Mere Quadrangle (15′). Latitude 41° 19.15′ N, Longitude 76° 41.52′ W.

A small long abandoned adit is located on the west side of the Highland Lake road, 1½ miles north of Tivoli.

Geology: Mineralization is confined to a thin lens of gray siltstone containing abundant small isolated plant fragments. Radioactivity at the outcrop ranges up to .7 mr/hr. Malachite is present along bedding surfaces along with minor amounts of crysocolla.

Prospect 25 *Location:* Beaver Lake, Sullivan County, Eagles Mere Quadrangle (15′). Latitude 41° 19.72′ N, Longitude 76° 36.85′ W.

Three small, collectively worked, prospects are located approximately one quarter mile west of Victor School, one and one half miles north of Strawbridge.

Geology: These prospects, numbers 25, 26, 27, were subjected to insufficient development work to yield the information necessary for a separate discussion of each.

Radioactivity, apparently associated with carbonaceous material, is only slightly above background at each prospect. Malachite encrustations along bedding planes are seen at all three. Shallow drilling at prospect 25 failed to show increased radioactivity at depth. Small dynamite pits at 26 to 27 also failed to disclose any significant deeper mineralization.

Prospect 26 *Location:* Beaver Lake, Sullivan County, Eagles Mere Quadrangle (15′). Latitude 41° 19.79′ N, Longitude 76° 36.98′. See Prospect 25.

Prospect 27 *Location:* Beaver Lake, Sullivan County, Eagles Mere Quadrangle (15′). Latitude 41° 19.85′ N, Longitude 76′ 37.13′ W. See Prospect 25.

Prospect 28 *Location:* Beaver Lake, Sullivan County, Eagles Mere

Quadrangle (15′). Latitude 41° 20.38′ N, Longitude 76° 38.00′ W.

A small long abandoned adit is located on the west side of the road, .4 miles NE of Rock Run Church.

Geology: Thin carbonaceous stringers are present within a gray shale lens overlain by gray siltstone. Isolated plant fragments, also mineralized, are present at the contact and within the siltstone. Chalcocite is present but no secondary minerals were detected. Highest radioactivity at the outcrop is on the order of .2 mr/hr.

Prospect 29 *Location:* Beaver Lake, Sullivan County, Eagles Mere Quadrangle (15′). Latitude 41° 21.38′ N, Longitude 76° 32.92′ W.

A mineralized outcrop is located on the north side of the Sonestown—Nordmont road, .25 miles from the junction with Rt. 220.

Geology: A greenish sandstone lens is incised into a reddish mudstone. A thin bed of grayish calcarenite marks the contact with the underlying mudstone. The calcarenite contains fragments of the reddish mudstone indicating that the latter is primary in origin. The reddish mudstone is leached to a gray color along fissures, a secondary effect. The greenish sandstone lens contains scattered plant fragments. Some irregular malachite staining is present within the sandstone. Radioactivity is approximately twice background count.

Prospect 30 *Location:* Dushore, Sullivan County, Monroeton Quadrangle (15′). Latitude 41° 30.90′ N, Longitude 76° 24.98′ W.

A filled excavation is located .4 mile west of the intersection of the Forksville road. The prospect was opened during the summer of 1957 and was refilled shortly thereafter.

Geology: Traces of malachite were noted along bedding surfaces at the time of the excavation. Radioactivity was scarcely above background. No macroscopic carbonaceous material was detected in the pit although it is undoubtedly present in the vicinity along with at least a minimum of sulfide mineralization from which the secondary malachite was derived.

Prospect 31 *Location:* Loyalsock Creek, Sullivan County, Powell Quadrangle (15′). Latitude 41° 30.58′ N, Longitude 76° 33.10′ W.

A radioactive outcrop is located on the north side of Rt.

87, 2 miles east of the small village of Millview.

Geology: The beds at this locality, in contrast to the other prospects in the general area, are inclined at a moderate angle (35° S). A lens of gray sandstone and shale about 3 feet thick contains the mineralized zone. A thin calcarenite lens is also present. It is overlain by a 2 inch seam of weathered carbonaceous material in which the radioactivity is concentrated. The highest readings obtained were 1 mr/hr. Some malachite is present along bedding surfaces. A shallow pit was dug at the top of the ledge above the road. This, however, failed to reach the mineralized area. Another pit was dug on the south side of the road, also with negative results.

Prospect 32 *Location:* Ladds Creek, Bradford County, Monroeton Quadrangle (15′). Latitude 41° 35.73′ N, Longitude 76° 27.18′ W.

An outcrop is located in the stream bed at the intersection of Ladds Creek and Overton Road, .5 miles West of Rt. 220 in New Albany.

Geology: A gray micaceous sandstone overlies a gray shale at water level in the stream bed. The sandstone contains the weathered remnants of coalified plant fragments ranging up to 18 inches in length. The underlying shale layer contains significant amounts of malachite along the bedding surfaces. Radioactivity is low, probably the result of the weathered condition of the carbonaceous material.

Prospect 33 *Location:* Beaver Run, Bradford County, Monroeton Quadrangle (15′). Latitude 41° 34.80′ N, Longitude 76° 27.73′ W.

A limited radioactive exposure is present on the southeast side of the unimproved road to Overton, 1.8 miles south of the junction with Rt. 220 in New Albany.

Geology: A gray flaggy siltstone and shale overlies a calcarenite lens which contains small plant fragments. Malachite and azurite are present along bedding surfaces. Radioactivity is about twice background.

Prospect 34 *Location:* Beaver Run, Bradford County, Monroeton Quadrangle (15′). Latitude 41° 35.20′ N, Longitude 76° 26.89′ W.

A small abandoned copper mine is located near a small waterfall, .3 miles upstream on a tributary to Beaver Run.

Geology: The mineralization is confined to a fissile gray

shale containing numerous isolated plant fragments as well as thin carbonaceous seams. At the outcrop this carbonaceous material is soft and unctuous as a result of weathering. In a recently opened adit parallel to the old mine entrance, fresh material was encountered. Its physical characteristics indicate that it approaches semi-anthracite coal in rank. This material is replaced by pyrite, and chalcocite. The radioactivity emanating from carbonaceous material is relatively low—between .1 to .2 mr/hr. at the outcrop. Malachite is relatively abundant along bedding surfaces in the shale.

The old mine was dewatered during the summer of 1957 and examined. No significant copper or uranium mineralization could be found. It is probable that the original lens or seam was entirely mined out.

Prospect 35 *Location:* Beaver Run, Bradford County, Monroeton Quadrangle (15′). Latitude 41° 35.30′ N, Longitude 28.46′ W.

Two mineralized outcrops are located on the same road as Prospect 33, 2.7 miles from the road junction.

Geology: At the first outcrop, a small lens of green siltstone overlies a thin calcarenite bed, underlain by a red shale. Mineralization is confined to a small seam of weathered carbonaceous material between the calcarenite and the siltstone. Chalcocite and secondary malachite are associated with the carbonaceous material. Radioactivity at the face ranges from .05 mr/hr. up to .1 mr/hr.

At the second outcrop, 175 feet to the south, malachite is present at the contact of a gray siltstone and the underlying gray shale. Some weathered plant fragments are present but radioactivity is only twice the normal background.

Prospect 36 *Location:* Sugar Run, Bradford County, Monroeton Quadrangle (15′). Latitude 41° 36.52′ N, Longitude 76° 23.50′ W.

A recently opened adit is located on a hillside above Sugar Run 1.3 miles southeast of Evergreen.

Geology: A bed of gray sandstone overlies a gray shale. Mineralization is confined to a carbonaceous seam several inches thick at the contact between these two units. Malachite and azurite occur as thin encrustations parallel to bedding in both the sandstone and the shale. The carbonaceous material is badly weathered and no sulfides were

identified. Radioactivity ranges up to .2 mr/hr. within the adit.

Prospect 37 *Location:* Forkston, Wyoming County, Meshoppen Quadrangle (15′). Latitude 41° 32.19′ N, Longitude 76° 07.45′ W.

A mineralized outcrop is present on the east side of road 100 yards north of bridge, north of the hamlet of Forkston.

Geology: This prospect is one of several previously described by Butler (1938). Several stringers of carbonaceous material are present in a channel deposit of siltstone and shale. Malachite and azurite are present along bedding surfaces. Radioactivity is relatively low; the highest reading obtained was three times background.

Prospect 38 *Location:* Robinson Pond, Wayne County, Waymart Quadrangle (7½′). Latitude 41° 32.26′ N, Longitude 76° 26.65′ W.

Three, long abandoned copper prospects are located on the farm of Joseph Millen, on an east facing ridge to the east of Robinson Pond.

Geology: All three adits were inaccessible so that only dump samples could be examined. In all three the mineralization is associated with plant fragments and carbonaceous seams found within gray sandstones and shales. Some chalcocite is present; malachite and azurite occur as bedding plane encrustations. Radioactivity ranges up to three times the normal background count.

Prospect 39 *Location:* Mt. Cobb, Lackawanna County, Olyphant Quadrangle (7½′). Latitude 41° 24.60′ N, Longitude 75° 30.51′ W.

Two abandoned copper prospects are at the base of Moosic Mt., 800 feet west of the 1,721′ bench mark at Mt. Cobb.

Geology: Both adits were flooded at the time of examination so that the general relationships could not be ascertained. However, the mode of occurrence appears to be the same as in other Catskill prospects. The lease holder reported a U.S. Bureau of Mines assay of .1% U.

Prospect 40 *Location:* Orangeville, Columbia County, Bloomsburg Quadrangle (7½′). Latitude 41° 04.20′ N, Longitude 76° 26.00′ W.

A prospect pit is located 2.9 miles south of the Rt. 93, 339 road junction in Orangeville.

Geology: The beds at this prospect dip 26° to the north. A

gray channel deposit of siltstone and shale is present in the roadcut. A shaft was dug at the top of the ledge above the road. However, the shaft had already been refilled at the time of examination. Examination of dump samples revealed little mineralization. Radioactivity was slightly above background.

Prospect 41 *Location:* Herndon, Northumberland County, Millersburg Quadrangle (15′). Latitude 40° 43.70′ N, Longitude 76° 48.83′ W.

A radioactive prospect is located on the crest of a south facing ledge above Mahanoy Creek at Kneass.

Geology: The mineralization is confined to a small carbonaceous stringer 2 inches thick and about 5 inches long. It is at the base of a gray siltstone unit, incised into a gray shale. Pyrite, bornite, chalcopyrite, and chalcocite replace the carbonaceous material. Malachite and azurite are secondary products. Radioactivity at the outcrop ranges up to 3 mr/hr.

Prospect 42 *Location:* Elliot Run, Huntingdon County, Orbisonia Quadrangle (15′). Latitude 40° 08.58′ N, Longitude 77° 58.54′ W.

A small excavation is located on the north side of the road, above Elliot Run, 1.5 miles from the Brownsville Crossroads.

Geology: The pit is approximately 8 feet wide and extends 20 feet into the ledge. An alternating sequence of red and gray siltstone and shales are exposed in the walls of the pit. A gray siltstone at the floor of the pit contains plant fragments up to several feet in length. Radioactivity is only three times background. Malachite is disseminated within this siltstone but the concentration is not significant.

Prospect 43 *Location:* Pikesville, Berks County, Boyertown Quadrangle (15′). Latitude 40° 25.43′ N, Longitude 75° 41.78′ W.

See page 51 of text.

APPENDIX B

Table 1

X-RAY SPECTOGRAPH ANALYSIS

Prallsville Ore (1)	Hendricks Island Ore (2)	Raven Rock Ore (3)	Prallsville Ore (1A)	Hendricks Island Ore (2A)	Raven Rock Ore (3A)	Hendricks Island Country Rock	Brownstone Quarry Country Rock
Uranium	Uranium	Uranium	Uranium	Uranium	—	—	—
?	Zirconium	Zirconium	Zirconium	Zirconium	Zirconium	Zirconium	Zirconium
Iron	Iron	Iron	Iron	Iron	Iron	Iron	Iron
Manganese	Manganese	?	Manganese	Manganese	—	Manganese	Manganese
Zinc	Zinc	?	?	Zinc	—	—	—
Arsenic	Arsenic	?	—	—	Arsenic	—	—
Copper ?	—	—	—	—	—	—	—
—	Lead	—	—	—	—	—	—
—	Titanium	—	—	Titanium	Titanium	—	Titanium

— Indicates the absence of an element

? Indicates the probable presence of an element

Table 2

X-RAY SPECTOGRAPHIC ANALYSIS

1 Mt. Pisgah (unmineralized conglomeratic arkose)	2 Mt. Pisgah (carnotite ore)	3 Mt. Pisgah (unoxidized primary ore)	4 Mt. Pisgah (heavy mineral concentrate)	5 Penn Haven Junction–Dev. (unoxidized primary ore)
Iron	Iron	Iron	Iron	Iron
Manganese	Manganese	Manganese	Manganese	Manganese
—	Zirconium	—	—	—
—	Uranium	Uranium	Uranium	Uranium
—	Vanadium	Vanadium	Vanadium	—
—	Lead	Lead	Lead	Lead
—	Zinc	Zinc	—	Zinc
—	—	—	—	Titanium
—	—	—	—	Selenium ?

— Indicates the absence of the element

? Indicates the probable presence of the element in minute quantity

Table 3

X-RAY SPECTROGRAPHIC ANALYSIS

Radioactive red siltstone "A"	Pale-Brown, Medium-Grained Sandstone "B"	Pale-yellowish–Brown Nonradioactive Sandstone "D"	Yellowish-Brown Mudstone
Uranium	Uranium	—	Uranium (trace)
Lead	Lead	—	—
Zinc	Zinc	Zinc	Zinc
—	Copper	—	—
Arsenic	Arsenic	—	Arsenic
Manganese	Manganese	Manganese	Manganese
Iron	Iron	Iron	Iron
Zirconium	Zirconium	Zirconium	Zirconium
Titanium	Titanium	Titanium	Titanium

1 Prospect 12 Ore	2 Prospect 12 Ore	3 Prospect 12 Ore	4 Prospect 12 Ore	5 Prospect 9 Ore	6 Prospect 9 Ore	7 Prospect 41 Ore	8 Prospect 34 Ore	9 Prospect 19 Ore
Uranium	—	—	—	—	—	Uranium	—	—
Copper	Copper	Copper	Copper	Copper	Copper	Copper	Copper	Copper
Iron	Iron	Iron	Iron	Iron	Iron	Iron	Iron	Iron
Manganese	—	—	Manganese	Manganese	Manganese	Manganese	Manganese	Manganese
Arsenic	Arsenic	Arsenic	—	—	—	Arsenic	—	Arsenic
—	Lead	Lead	Lead	Lead	Lead	Lead	Lead	—
—	Barium	Barium	Barium	Barium	Barium	Barium	Barium	Barium
—	—	—	—	—	—	—	—	Titanium
—	—	—	—	—	—	—	—	—

10 Pyrite from Red Rock Mt.	11 Prospect 23 Ore	12 Prospect 12 Coal	13 Prospect 34 Coal	14 Prospect 30 Gray Sandstone	15 Prospect 30 Red Sandstone	16 Prospect 9 Red Shale	17 Prospect 9 Gray Shale
—	Uranium	Uranium	—	—	—	Uranium	Uranium
—	Copper	Copper	Copper	—	—	—	Copper
Iron	Iron	—	Iron	Iron	Iron	Iron	Iron
—	Manganese	Manganese	Manganese	Manganese	Manganese	Manganese	Manganese
Arsenic	Arsenic	Arsenic	Arsenic	Arsenic	—	—	—
—	Lead	—	—	—	—	—	—
—	Barium	Barium	Barium	—	—	—	—
—	Titanium	—	—	Titanium	Titanium	Titanium	Titanium
—	—	—	—	Zirconium	Zirconium	Zirconium	Zirconium
—	—	—	—	—	—	Zinc ?	—

— Indicates absence of the element.

? Indicates the probable presence of the element in minute quantities.

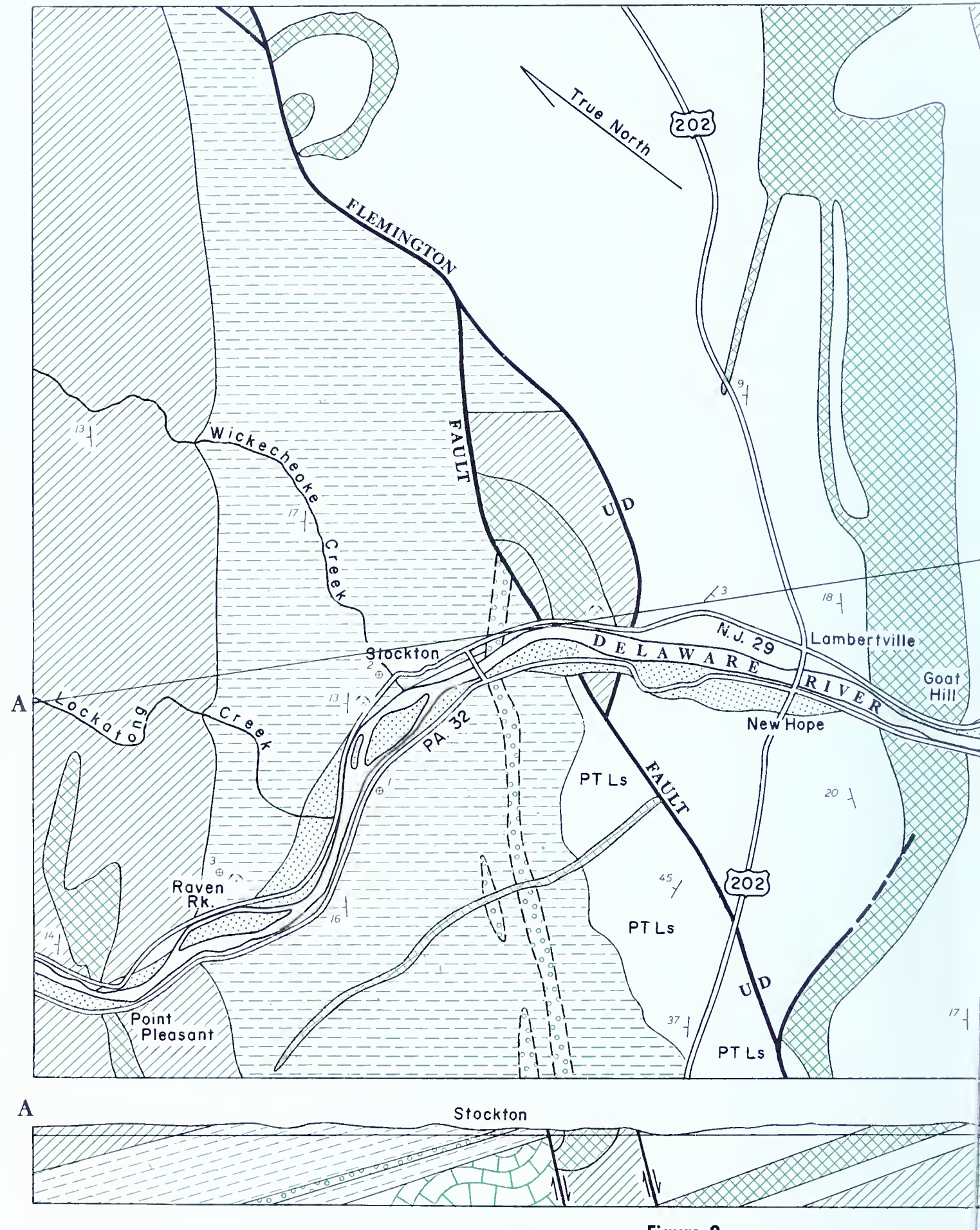
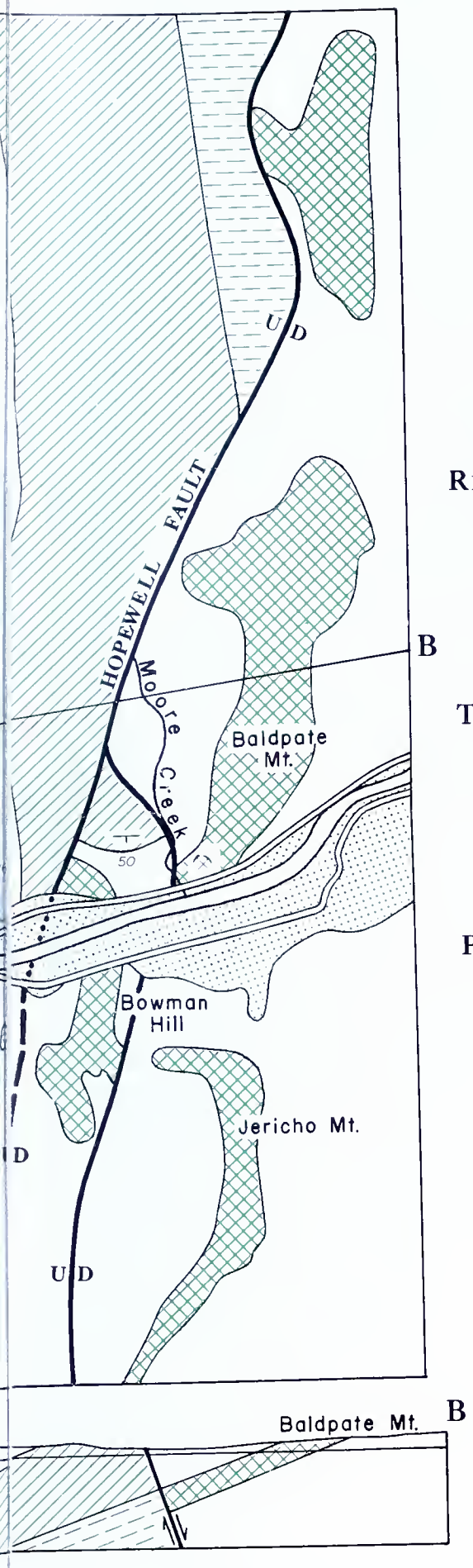

True North
202
FLEMINGTON
FAULT
U D
Wickecheoke Creek
Stockton
N.J. 29
DELAWARE RIVER
Lambertville
Goat Hill
New Hope
A
Lockatong Creek
PA 32
PT Ls
FAULT
202
PT Ls
U D
PT Ls
Raven Rk.
Point Pleasant
A
Stockton

Figure 2

GEOLOGIC MAP
OF THE
STOCKTON–LAMBERTVILLE AREA

After D.B. McLaughlin



LEGEND

RECENT AND PLEISTOCENE		Alluvium and Outwash
TRIASSIC	IGNEOUS	Diabase Basalt (bs)
	BRUNSWICK	Red shale and Argillite
	LOCKATONG	Black Argillite and shale
	STOCKTON	Arkose and Conglomerate
PRE-TRIASSIC	PALEOZOIC	Limestone (Ls) PT Ls

Road

Fault

45 Dip and strike

⊕ Uranium occurrence

SCALE

0 1 2 3 Miles

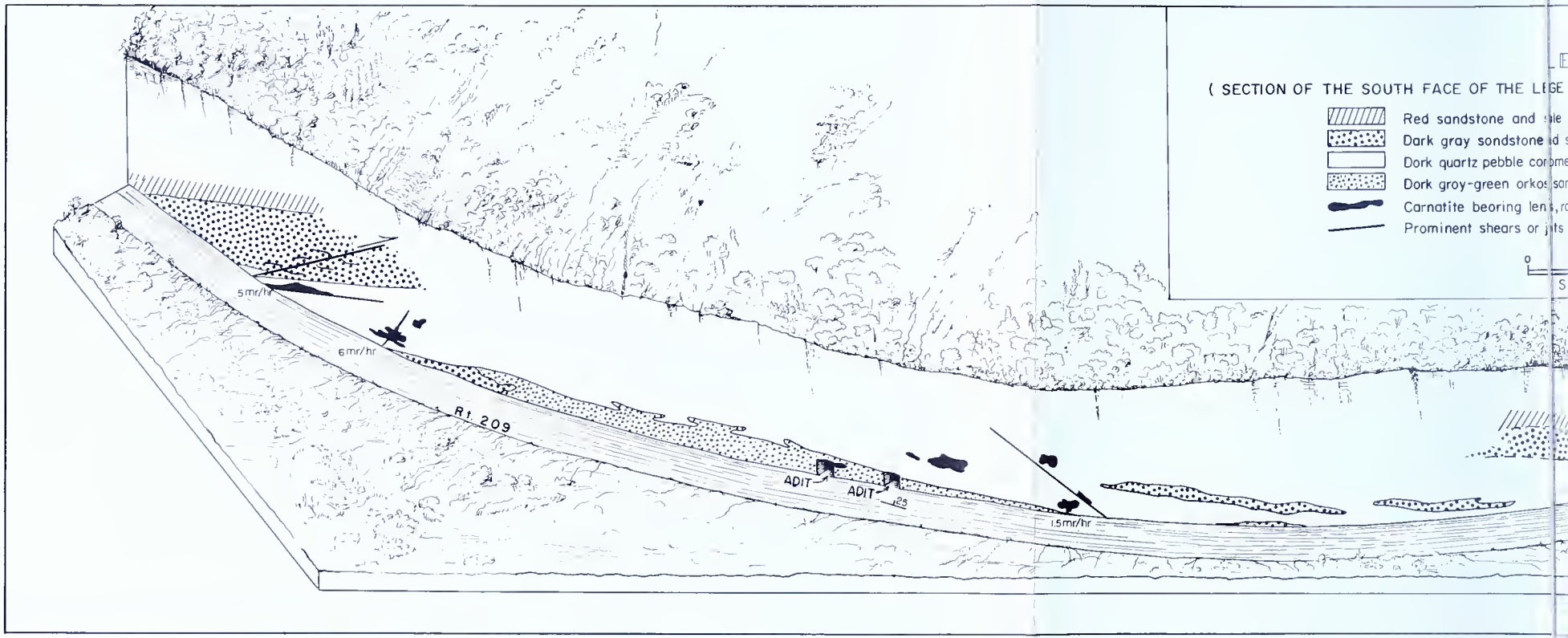
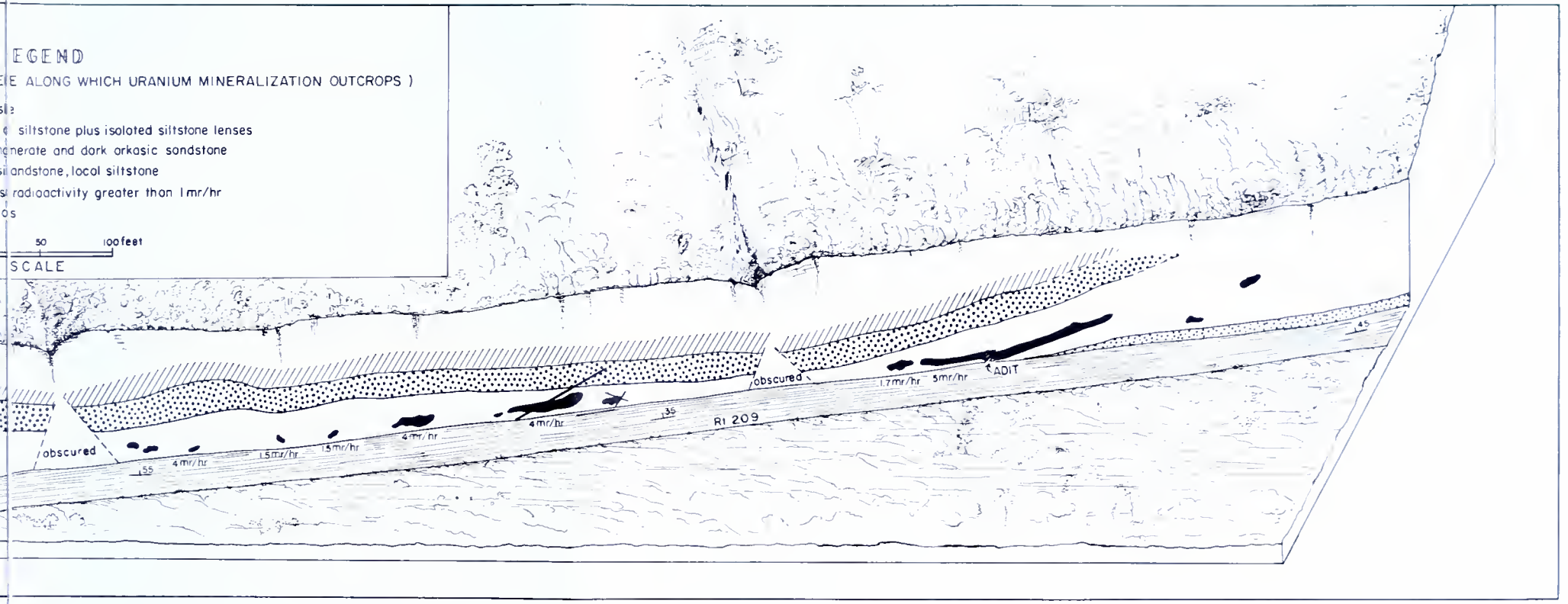

(SECTION OF THE SOUTH FACE OF THE LEGE
Red sandstone and sle
Dark gray sandstone
Dork quartz pebble co
Dork groy-green orko
Carnatite beoring len
Prominent shears or
0
S
5 mr/hr
6 mr/hr
R1 209
ADIT
ADIT
25
1.5 mr/hr

Figure 4. M



M Pisgah occurrence.

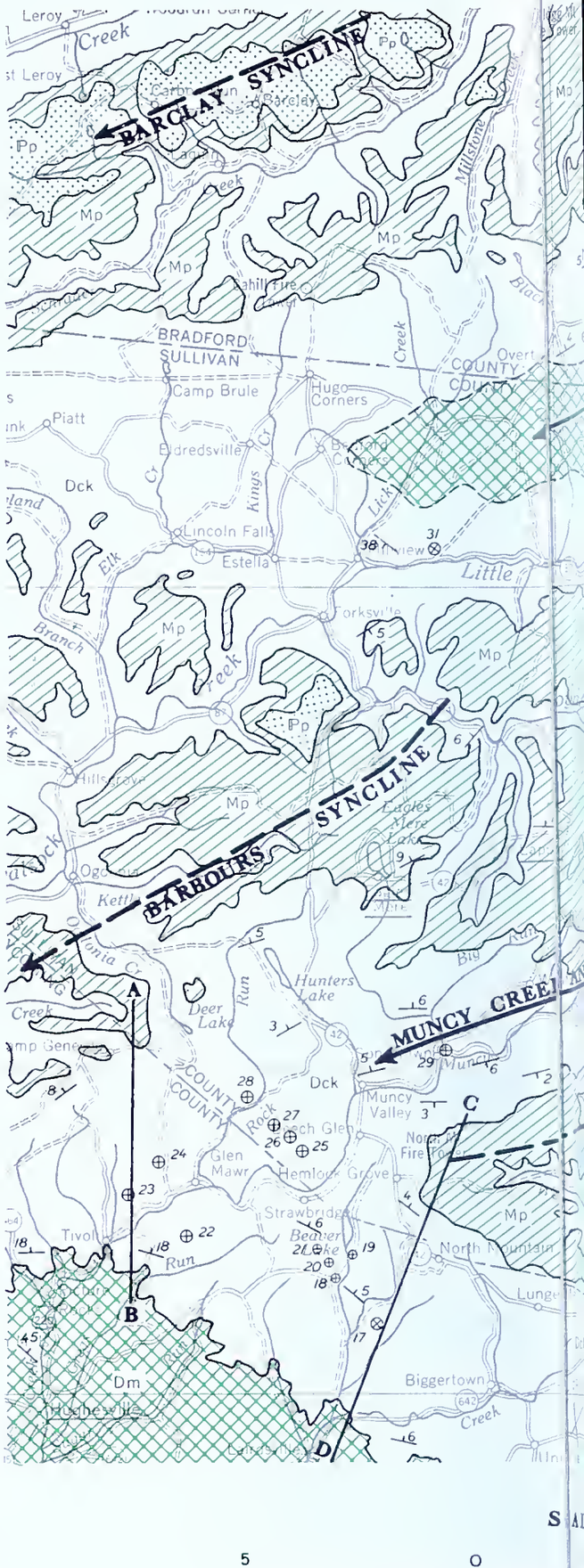


Figure 7. Geologic map of the N uranium areas.

Geology taken from State Geologic Map (1960) with modifications by the author

SCALE

5 10

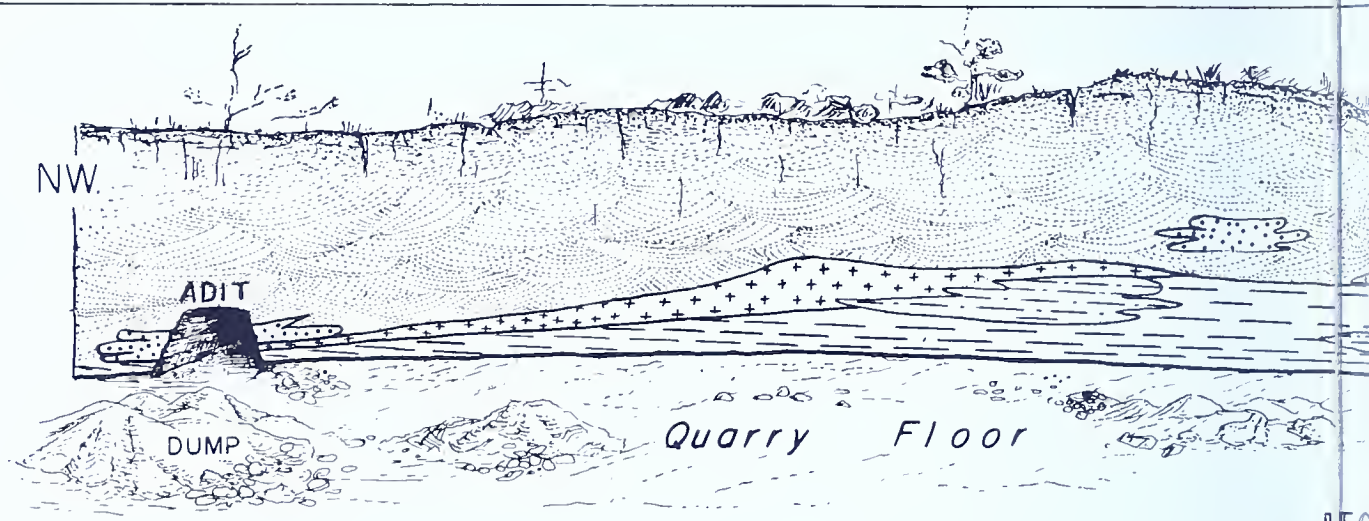
LEGEND

Anticlinal Axis

Synclinal Axis

⊕ 28 Uranium Prospect

A——B Line of cross section



(DIAGRAM REPRESENTS A NW–S TR

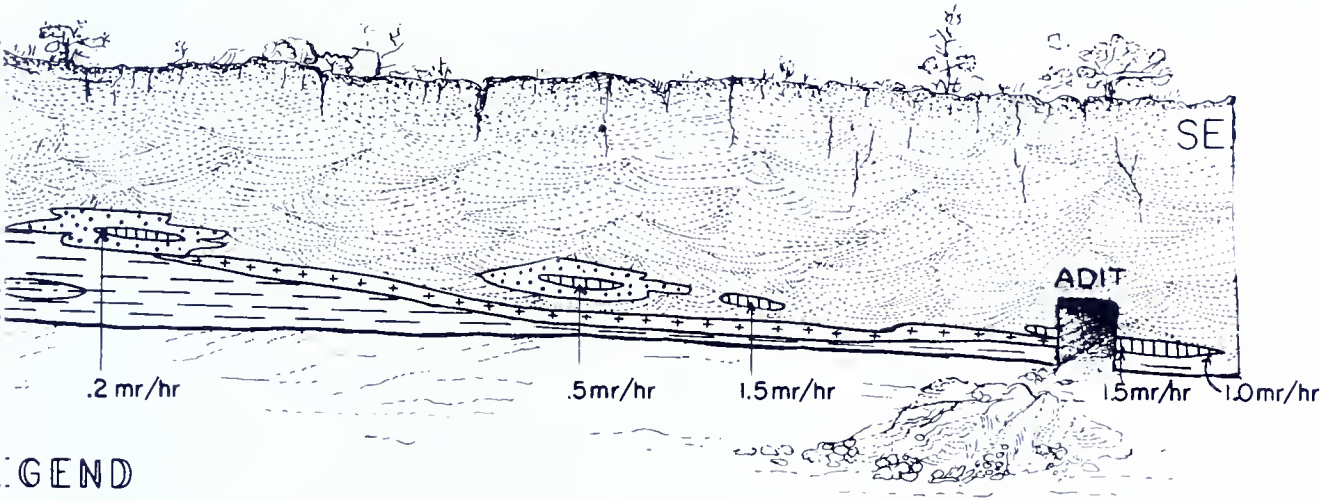
Crossbedded siltstones mostly reddish, minor gray

Predominantly grayish–greenish lenses within the above

Reddish to grayish clay gall calcarenite

0

Figure 13. Prospect 2, B



.GEND

TRENDING LEDGE 20 TO 30 FEET IN HEIGHT)

Reddish laminar silts

Red shale

Thin carbonaceous seam 1 to 2 inches thick, coaly material replaced by copper sulfides, secondary uranium minerals present locally.

SCALE

20 Feet

, Beaver Lake Area.

POCKET

M—43